ARCTIC TECHNOLOGY DEVELOPMENT AT THE UNIVERSITY OF WASHINGTON

Final Report

1 July 1971 - 1 August 1972

AD 748228

THIS RESEARCH WAS SUPPORTED BY THE ADVANCED RESEARCH PROJECTS AGENCY OF THE DEPARTMENT OF DEFENSE AND WAS MONITORED BY ONR UNDER CONTRACT NO. N00014-67-A-0103-0016.

ARPA Order Number:	1668
Program Code Number:	ON10
Contractor:	Board of Regents University of Washington Seattle, Washington 98195
Period of Performance:	1 June 1970 - 30 September 1972
Amount of Contract:	$742,940.00
Contract Number:	N00014-67-A-0103-0016
Principal Investigator:	Stanley R. Murphy, Director Division of Marine Resources University of Washington (206) 543-6600
Scientific Officer:	Director, Ocean Technology Programs Ocean Science and Technology Division Office of Naval Research, Dept. of the Navy Arlington, Virginia 22217

11 SEPTEMBER 1972

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Applied Physics Laboratory, University of Washington, 1013 NE 40th, Seattle, Wash. 98105	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3. REPORT TITLE

ARCTIC TECHNOLOGY PROGRAM AT THE UNIVERSITY OF WASHINGTON (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report, 1 July 1971 - 1 August 1972

5. AUTHOR(S) (Last name, first name, initial)

Murphy, Stanley R.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
11 September 1972	95	10

8a. CONTRACT OR GRANT NO. N00014-67-A-0103-0016 b. PROJECT NO. ARPA Order Number: 1668 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) -- 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) Appendix A to this report is APL-UW 7219

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency 1400 Wilson Blvd. Arlington, Virginia 22209

13. ABSTRACT

A synopsis of the sponsored arctic technology development at the University of Washington is presented. This includes a description of technical management activities, a description of several concepts for new arctic technology, and a description of the development and successful arctic operation of an under-ice research submersible (UARS). An appendix gives a complete technological description of the UARS system. (U)

-A-

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
submersible, unmanned arctic research						
acoustics, under-ice						
under-ice surface profiler						
ice-coring, thermal						
arctic acoustic buoys						
arctic research technology						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

ARCTIC TECHNOLOGY DEVELOPMENT AT THE UNIVERSITY OF WASHINGTON

Final Report

1 July 1971 - 1 August 1972

THIS RESEARCH WAS SUPPORTED BY THE ADVANCED RESEARCH PROJECTS AGENCY OF THE DEPARTMENT OF DEFENSE AND WAS MONITORED BY ONR UNDER CONTRACT NO. N00014-67-A-0103-0016.

ARPA Order Number:	1668
Program Code Number:	ON10
Contractor:	Board of Regents University of Washington Seattle, Washington 98195
Period of Performance:	1 June 1970 - 30 September 1972
Amount of Contract:	$742,940.00
Contract Number:	N00014-67-A-0103-0016
Principal Investigator:	Stanley R. Murphy, Director Division of Marine Resources University of Washington (206) 543-6600
Scientific Officer:	Director, Ocean Technology Programs Ocean Science and Technology Division Office of Naval Research, Dept. of the Navy Arlington, Virginia 22217

11 SEPTEMBER 1972

CONTENTS

ARCTIC TECHNOLOGY DEVELOPMENT
AT THE UNIVERSITY OF WASHINGTON

FINAL REPORT

I. INTRODUCTION

The ARPA Arctic Technology program, now two years old, has become an important catalyst to the arctic scientific community at the University of Washington. It has provided a means for the innovative experimentalist to present his ideas for the improvement of field operations and equipment and has given both the scientist and the strategic planner a glimpse of what can be accomplished with high technology in a hostile environment. The program was conceived as a means of bringing together the wealth of scientific and technical experience which the University faculty and staff possess in polar research. This concerted intellect might then be brought to bear on arctic problems and defense concepts of interest to ARPA. To initiate the program an Arctic Technology Advisory Group was established and a coordinator assigned to convene the group on occasion to generate or review new approaches to the resolution of arctic problems, or to respond rapidly to specific requests by ARPA for consultation. Simultaneously, a "high risk-high gain" type of technical development project was initiated to provide an environment in which new ideas could successfully spawn. This project was aimed at the development of a prototype, untethered, unmanned submersible which could operate quietly over extended ranges and collect data in close proximity to the under-ice surface. This work culminated in mid-May with the successful demonstration of such a submersible system. A detailed discussion of that project follows in the next section.

We found that many of the essential elements of the submersible system had spin-off potential and have since evolved into widely used systems. Such serendipity can be ascribed to the thermal ice corer and the submersible tracking buoys which have become, respectively, the acknowledged standard technique for cutting large access holes in pack ice and the accepted design approach for a variety of weather and scientific arctic buoy systems.

This report describes the activities which have been carried out this year in the Arctic Technology Program and refers to accomplishments of last year where they relate to present work. Although the contract actually extends two months beyond the reporting period, essentially all of the research has been completed and is discussed herein.

II. ANNUAL PERFORMANCE SUMMARY

A. Unmanned Arctic Research Submersible (UARS) System

The UARS system comprises two major elements--an unmanned submersible which serves as a mobile instrument carrier and a remote tracking, guidance and recovery system. Our objective in this program is to provide the technological capability to conduct under-ice research with unmanned, untethered vehicles and to demonstrate vehicle performance. The first year of the program was devoted to design, with test hardware limited to breadboard assemblies. During the present year, the system has been fabricated, tested, and its performance demonstrated in the arctic under-ice environment. The goals of the program were successfully achieved. The following brief summary describes the existing system.

The UARS is a compact vehicle which weighs 900 lb in air and has a length of approximately 10 ft and a diameter of 19 in. The design speed of the vehicle is 3 kn (speeds of 3 and 3.7 kn are presently available). Low speeds were selected since control system problems are more crucial at this end of the velocity spectrum. Higher speeds can be obtained by motor substitution. The main batteries supply sufficient energy for a 10-hour run. In addition to acoustic instrumentation for measuring physical phenomena, the vehicle carries several other acoustic systems which are used for communication (both to and from UARS), tracking, homing and collision avoidance. The latter is necessary because of potential pressure ridge keel projections to the desired operating depth of the UARS. The initial instrumentation suite of UARS includes an array of acoustic sensors incorporated into an ice profiler system that is capable of measuring the elevation of the ice under-surface to an accuracy of 0.3 ft.

The vehicle is launched in a horizontal attitude after being lowered through a 4 x 12 ft hole in the ice. The motor is started before release from a special launch rack; the UARS rises about 2 ft before full depth control is achieved and begins its climb or dive to its preset initial depth. New procedures for making the launch hole in thick arctic ice were developed and used effectively in the program.

The position of the UARS is known at all times from information derived from an acoustic tracking system. The principal elements of this system are: (1) a projector aboard the UARS which transmits a unique pulse code; (2) an array of four or more hydrophone-decoder-RF telemetering buoys arranged in a pattern within the experiment or survey area; (3) two baseline acoustic transducers within the experiment area which survey the location of the tracking hydrophones and provide a coordinate reference axis; (4) the timing units, data processors and computer system which provide the real-time interpretation of acoustic information and position calculations. The real-time position information, along with data measured by UARS, is relayed to the experimenter by a coded acoustic tracking pulse and provides the information for intelligent remote control of the

UARS during the experiment runs. The hydrophones are designed as free-floating buoys, but are usually frozen in place, weather permitting. At the power levels and frequencies used, the acoustic tracking/communication link has an effective range in excess of 8000 ft under typical arctic ambient noise conditions. The command communication and tracking systems use the same acoustic frequency, 50 kHz. Up to 16 command functions are presently available for controlling UARS.

The UARS is recovered by ensnaring it in a net. The capture net contains an acoustic beacon which the UARS homing system is commanded to seek at the appropriate time. In the event that command communication with the UARS is lost for a preset period of time, the homing system will automatically activate and UARS will begin a search for the beacon. At present power levels, the effective range of the homing system is 2-3 miles under typical arctic noise background conditions. Internally programmed logic, an inertial and depth-sensing guidance system and the command/tracking receivers provide retrieval redundancy. However, in the event of massive power interruption or other catastrophic failure, a further retrieval capability is provided. The submersible has positive buoyancy and will rise to the undersurface of the ice and automatically lower an acoustic beacon to aid an over-the-ice search party. The system includes a beacon location device and appropriate tools for emergency recovery of the vehicle once it is located.

The UARS has about 150 pounds of reserve buoyancy which can be devoted to instrumentation over and above that already installed. There are several ports in the body which allow oceanographic, optical, and acoustic instrumentation to be mounted without major effort. An internal digital recording system has ample capacity for high resolution recording during the run (1000 binary bits per second for 10 hours). After test runs, internally recorded data and externally measured position data are merged on one tape so that spatial-temporal correlation of observed phenomena can be accomplished.

The first part of this year's effort was spent in system fabrication. The complete system configuration was achieved in late February when tests of the UARS began in Lake Washington. The usual interaction problems of complex systems were largely resolved during the 20-run test program. This testing program was concluded in late March and the entire system deployed to Fletcher's Ice Island (T-3) for full scale arctic testing. The final development testing progressed in an orderly manner, beginning with tethered operations in the vicinity of the hydrohole and proceeding to untethered vehicle runs at full design distances. For initial check-out, the UARS vehicle was tethered at depths ranging to 300 ft below the under-ice surface at the hydrohole (28 feet deep).

The vehicle's first free run in the under-ice environment was on 3 May. This run lasted slightly over one hour. Almost all acoustic systems indicated some problem areas related to the environment. The analysis and subsequent experimentation led to resolution of these problems. The final run of the series was made on 9 May and it was a complete success. The vehicle was operated within a radius of approximately one half

mile from the launch hydrohole and was acoustically commanded to follow a rosette-type run pattern. The run distance was in excess of 17 miles, and the run duration was greater than 4 hours. The acoustic tracking and communication from the vehicle were excellent throughout the run. Over 200,000 position-correlated profile measurements of the under-ice surface were made. Pressure ridge keels to depths exceeding 75 feet were observed.

The vehicle recovery system was successful and there was no need to employ the emergency recovery system. At the conclusion of the field tests all tracking instrumentation was recovered from the ice, using the thermal coring technique developed in this program. The launch/recovery hydrohole (4' x 12' x 28' deep) was also made using this device.

While the purpose of the arctic tests was to complete the UARS system development, nevertheless, new and basic data were obtained by the instrumentation suite and supporting measurements.

On UARS runs, the elevation of the under-ice surface was measured at about 1-ft intervals to an accuracy of about 0.3 ft. A level traverse (conventional surveying techniques) was made over a selected UARS track about a mile in length. The ratio of ice surface to bottom elevations with respect to sea level for new pressure ridging was observed to be nearly 1 to 7 for five first-year pressure ridges (keel depth to 55 feet) and for one multiyear pressure ridge. This contrasts with ratios of 1 to 3 and 1 to 5 previously reported in the literature.

Temperature observations made with the UARS traveling on an isobaric trajectory indicate that the water column near the surface (45 meters) tended to be displaced vertically by the gross topography of the under-ice surface. (When the nominal temperature gradient at observation depth is multiplied by the corresponding elevation change of the under-ice surface, the resulting value agrees very well with the measured temperature variation.)

B. Technical Program Management

The work of the Arctic Technology Advisory Group (ATAG) has continued throughout this year in a pattern similar to the past. Topics of discussion at the meetings have ranged from a general review of the elements of arctic mobility to the identification of specific technology that could revolutionize our capability to keep the Arctic under constant surveillance or prosecute submarine contacts. Periodically, the Group Coordinator provided oral briefings to the ARPA Advanced Engineering Office, Tactical Technology Office and the Strategic Technology Office on the recommendations made by the ATAG. Based upon the interest expressed in ARPA, ATAG members have developed and submitted detailed technical descriptions suitable for project initiation. These included recommendations for the development of an Arctic Ocean ice terrain vehicle; the development of a system of artificial polynyas or liquid aircraft landing surfaces which could facilitate rapid access throughout the Arctic in any season; and the development of a remotely interrogated secure bottom-mounted or surface-piercing surveillance buoy network. At this writing

other technical descriptions are being prepared which cover, (1) the use of the UARS vehicle as a model for the development of a non-acoustic submarine trailing (wake-following) capability, (2) the use of the UARS tracking and control system as a unique under-ice test range for torpedo development, and (3) the employment of the UARS as a multifrequency acoustic projector (target) to operate with an arctic surveillance network.

During the year, members of the ATAG were invited to participate in several ARPA-sponsored planning conferences. These included the presentation of a paper on the UARS system at the Arctic Logistics Support Technology Symposium (November 1971), assistance to the Office of Naval Research in planning Naval Arctic Research Laboratory activities (December 1971), a technology status report given to the National Academy of Science Arctic Program Review Committee (December 1971), presentation of a paper on "Application of Acoustic Shear Waves in Ice" to the annual meeting of the Acoustical Society of America (April 1972), and an NSF-sponsored technical discussion with scientists from the USSR during the arctic trials of the UARS system (May 1972). We have been advised that a member of the ATAG will also be included in a group of specialists meeting at RAND to review arctic defense-related topics (August 1972). Early in the year a proposal was also submitted to ARPA to sponsor, at the University of Washington, a joint U.S.-Canadian arctic defense planning conference. It appeared that such a conference would have many benefits to each nation and could define a cooperative program of complementary research. Unfortunately, changes in program management and other administrative actions resulted in the proposal being shelved.

Members of the ATAG have worked steadily to assemble a group of sponsors for a research program employing the UARS during the coming year. All those contacted have stated a strong need for the unique data gathering capability of the vehicle in their programs; nevertheless, it has not been possible for them, collectively, to identify the necessary funding for a joint use program. The organizations that have indicated a need for or an interest in employing UARS include the Office of Naval Research, the Naval Ordnance Systems Command, the Naval Material Command (Ocean Engineering Branch), the Naval Ordnance Laboratory, the U.S. Army Cold Regions Research and Engineering Laboratory, the National Science Foundation, the Canadian Department of Environment, Sun Oil Company, and Amoco Production Company. The applications discussed with these agencies and organizations have ranged from purely scientific to commercial to purely defense and surveillance related functions. Many of the research interests could be accommodated using the same instrumentation and sensors. The impressive variety of research missions which are feasible with the UARS can be seen from the listing below. In addition to these unclassified uses a number of classified missions for UARS have also been discussed with ARPA.

1. Wake Detection Modeling
2. Surveillance Network Target System
3. Arctic Torpedo Development and Testing
4. Oceanographic Data Collection Near the Ice Surface
5. Oceanographic Data Collection in the Shallow Marginal Arctic Seas

6. Near-Ice Tactical Acoustics Research
7. Ice Optical Transmission/Thickness Correlations
8. Micromagnetic Mapping of Shelves and Sills
9. Under-Ice Seismic Survey System

Interest in the wake-detection application for UARS and the surveillance buoy network has come from the ARPA Strategic Technology Office. ATAG members briefed representatives of that office several times during our Arctic Technology Program, and most recently after the successful UARS arctic field tests and our successful placement of a buoy matrix (800 kilometers in diameter) in the central Arctic to collect atmospheric data via the Nimbus-B satellite for NOAA and NSF. The potential for using this buoy array for acoustic data collection was discussed.

Locally the Arctic Technology Advisory Group has sponsored a number of "brainstorm" sessions and seminars on practical operations in the Arctic such as techniques and applications of explosives in ice clearance, and use of modular foam-filled panels for habitat construction techniques in remote areas. Thus, it is quite clear that this ARPA-sponsored advisory group has had a most stimulating effect on the arctic community at the University as well as on those interested in the polar regions throughout the Federal government. The only major disappointment which has been experienced was the inability of the Group to assemble a consortium of sponsors to fund jointly the UARS system for scientific data collection during the coming year. Although enthusiasm was high among all concerned, their scientific budgets were not geared to absorb the costs of utilizing the high technology represented by the UARS system. After many meetings with the scientific program managers and the submission of a formal proposal to the Office of Naval Research, it became clear that the needed funds simply were not available within the collective budgets of potential sponsors.

III. CONCLUSIONS

The concept and application of the ARPA Arctic Technology Program has, in the view of the University of Washington, proven to be both sound and successful. All goals which were established for the program have been met or exceeded and a wide range of beneficial by-products were developed. These have been employed with acknowledgment to ARPA for the vision of sponsoring defense-related arctic technology development.

The Arctic Technology Advisory Group has served as an excellent forum for the discussion and evaluation of the nation's arctic research and operational needs. The meetings have benefited from the participation of scientists from the NSF AIDJEX coordination office also located at the University of Washington. ARPA has been provided with a broadly qualified group of scientists, engineers, and program managers through the ATAG and has received numerous recommendations to undertake arctic projects with defense implications. Contacts made through the ATAG have stimulated international interest in cooperative arctic work. Most significant in this regard has been an offer by the Canadian Department of Environment to provide arctic support at Greely Sound for a research program involving the

UARS system. The successful operation of UARS has proven the feasibility of developing miniature, remotely controlled, unmanned submarines to perform hazardous tasks or special missions where size must be minimized. The unique data collection capability of the system is also sought by a variety of scientific programs in the Arctic. ARPA's willingness to support high-risk technology has thus paid off with important dividends in an area where our defense capability needs a strong boost.

APPENDIX A

Unmanned Arctic Research Submersible (UARS) System Development and Test Report

by

R. E. Francois

W. E. Nodland

Applied Physics Laboratory
University of Washington

TECHNICAL REPORT FOR PERIOD ENDING 1 AUGUST 1972

DATE OF ISSUE: 11 SEPTEMBER 1972

TECHNICAL REPORT NO. APL-UW 7219

Contract N00014-68-A-0103-0016
Monitored by Office of Naval Research

Sponsored By:

Advanced Research Projects Agency
ARPA Order No. 1668

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U.S. Government.

Reproduction in whole or in part is permitted for any purpose of the United States Government.

CONTENTS

FIGURES

FIGURES (cont.)

TABLES

1. INTRODUCTION

1.1 BACKGROUND

As part of the ARPA-sponsored Arctic Technology Program at the University of Washington, the Division of Marine Resources has been administering the development of an unmanned, untethered submersible system for research work under arctic ice. A major portion of this effort has involved the University's Applied Physics Laboratory where a somewhat similar system, configured for use at deep depths in the open ocean, was developed and has been in use for over 12 years. This type of submersible allows the exploration of the horizontal distribution of phenomena in situations where its capabilities provide a unique approach or where use of other platforms, such as manned submarines, would be unfeasible within available technology or too expensive or dangerous.

The Unmanned Arctic Research Submersible (UARS) system has been developed to allow systematic exploration of the near-surface, under-ice region since much of the phenomena of operational and scientific significance is directly related to the presence of the ice canopy. One investigation, relating to the canopy itself, is an under-ice profiling mission, shown in an artist's sketch, Figure 1.1. Such studies have an important bearing on establishing the possibility of routine submarine transport operations in the Arctic. This possibility depends upon the nature of the pressure ridge keel projections from the under-ice surface and upon navigational and ice avoidance sonar systems which can reliably detect the keels. If feasible, such sonar systems would permit reasonably high speed operation in close proximity to the ice and bottom in the the extensive marginal seas of the Arctic. UARS can serve as a mobile acoustic projector test platform for the development of these sensors, and the test data can be correlated with the observed under-ice topography as measured by UARS's profiler instrumentation. Similar measurements can assist in establishing the differences in ice reverberation and target signatures for both search sonar and submarine defensive systems.

One common measurement which should always be made for correlation with other observed data when operating under the ice is the topographical nature of that surface. This parameter is directly or indirectly related to such a wide range of oceanographic and biological properties that the UARS system configuration was developed with this capability.

2. DEVELOPMENT PROGRAM AND SYSTEM SYNTHESIS

2.1 PROGRAM PLAN AND EXECUTION

A two-year development program was established for the UARS system with the objectives of advancing technology to permit remotely controlled under-ice observations and demonstrating the system's capability. System functional and detail design was to be completed during the first year

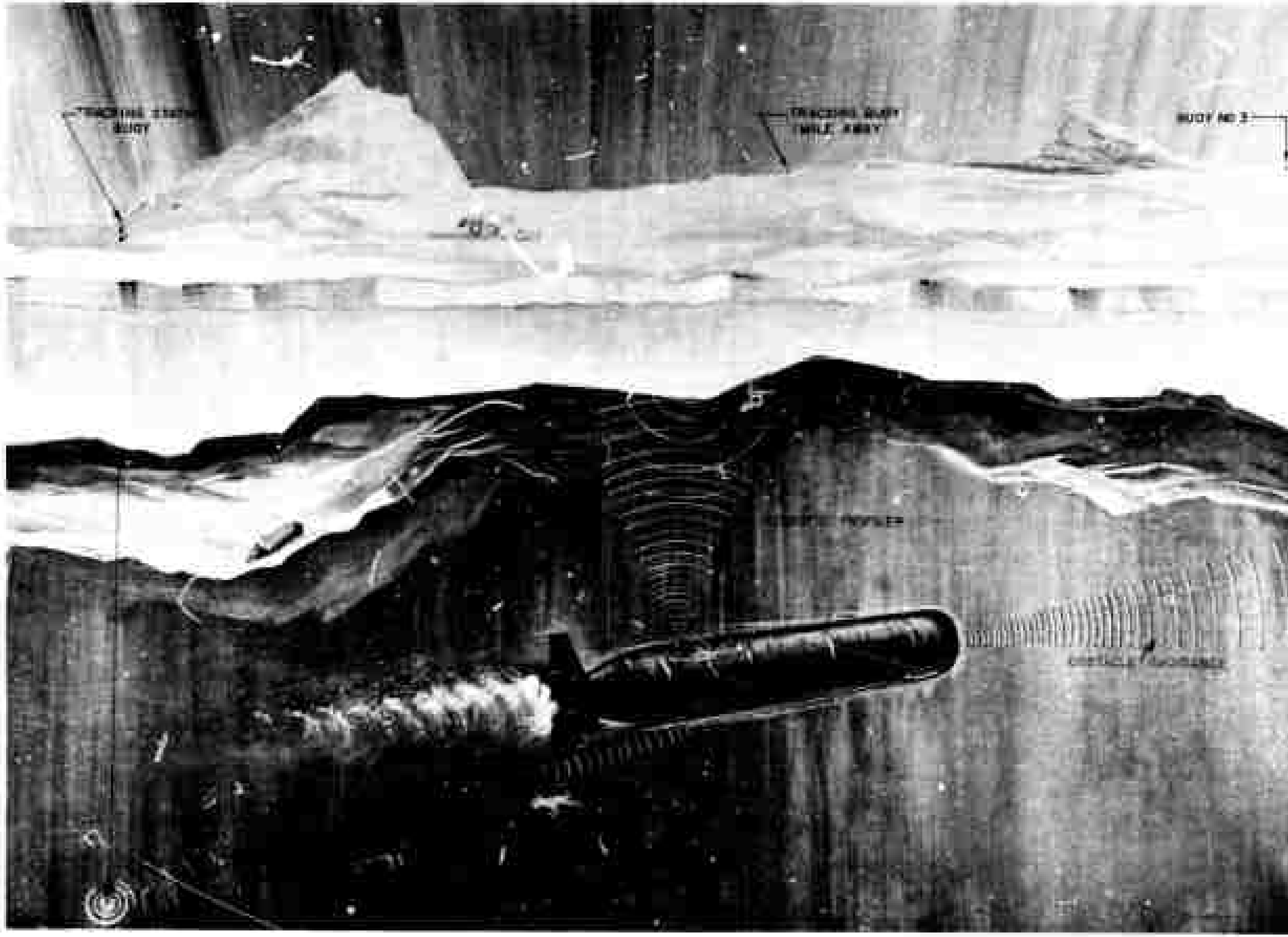


Figure 1.1. Unmanned Arctic Research Submersible (UARS) Performing an Under-Ice Profiling Mission

(ending in June 1971), while fabrication and test of the complete system was to be accomplished in the second year of the program. With the successful completion of the development tests in the Arctic during May 1972, these objectives were achieved.

During the first year of the program a small amount of hardware, primarily acoustic instrumentation and signal processors, was fabricated for test purposes. In April 1971, this instrumentation was taken to Fletcher's Ice Island (T-3) in the central Arctic to investigate the attenuation properties of the medium, the signal return characteristics of the ice undersurface, and the effectiveness of our system's signal processing and validation logic.

During the summar and fall of 1971, the manufacture, assembly and bench testing of the UARS system components were begun. We had expected to be ready for full-scale tests in local waters by late December, but these tests were delayed because of unexpectedly long delivery times on many common components. Full-scale tests in Lake Washington (limited in scope by environmental conditions) were conducted from mid-February through 29 March. The equipment was shipped to T-3 and arrived there on 10 April. An advance party had set up an operating camp at T-3 during the preceding 20 days, but it was another 2 weeks before in-water tests of the entire system could begin. Tethered runs were made to systematically check out the system. The first under-ice free run of the UARS was made on 3 May, and the last free run, in excess of 4 hours, was made on 9 May. During this final run, the complete UARS instrumentation suite was in operation and measurements of the profile of the under-ice surface and temperature along the isobaric path were made five times each second. These measurements are the first of this kind and provide basic and new information.

2.2 BRIEF DESCRIPTION OF SYSTEM

The UARS system consists of a torpedo-shaped vehicle for carrying instruments for basic or applied research, and several supporting subsystems for launching, tracking, commanding, and recovering the vehicle. These systems are described in detail in Sections 4 and 5 of this report --however, a brief review of the complete system is presented here.

The UARS is a compact vehicle which weighs 900 lb in air and has a length of approximately 10 ft and a diameter of 19 in. The design speed of the vehicle is 3 kn (speeds of 3 and 3.7 kn are presently available). Low speeds were selected since control system problems are more crucial at this end of the velocity spectrum. Higher speeds can be obtained by motor substitution. The main batteries supply sufficient energy for a 10-hour run. In addition to acoustic instrumentation for measuring physical phenomena, the vehicle carries several other acoustic systems which are used for communication (both to and from UARS), tracking, homing and collision avoidance. The latter is necessary because of potential pressure ridge keel projections to the desired operating depth of the UARS. The initial instrumentation suite of UARS includes an array of acoustic sensors incorporated into an ice profiler system that is capable of measuring the elevation of the ice under-surface to an accuracy of 0.3 ft.

The vehicle is launched in a horizontal attitude after being lowered through a 4 x 12 ft hole in the ice. The motor is started before release from a special launch rack; the UARS rises about 2 ft before full depth control is achieved and begins its climb or dive to its preset initial depth. New procedures for making the launch hole in thick arctic ice were developed and used effectively in the program.

The position of the UARS is known at all times from information derived from an acoustic tracking system. The principal elements of this system are: (1) a projector aboard the UARS which transmits a unique pulse code; (2) an array of four or more hydrophone-decoder-RF telemetering buoys arranged in a pattern within the experiment or survey area; (3) two baseline acoustic transducers within the experiment area which survey the location of the tracking hydrophones and provide a coordinate reference axis; (4) the timing units, data processors and computer system which provide the real-time interpretation of acoustic information and position calculations. The real-time position information, along with data measured by UARS, is relayed to the experimenter by a coded acoustic tracking pulse and provides the information for intelligent remote control of the UARS during the experiment runs. The hydrophones are designed as free-floating buoys, but are usually frozen in place, weather permitting. At the power levels and frequencies used, the acoustic tracking/communication link has an effective range in excess of 8000 ft under typical arctic ambient noise conditions. The command communication and tracking systems use the same acoustic frequency, 50 kHz. Up to 16 command functions are presently available for controlling UARS.

The UARS is recovered by ensnaring it in a net. The capture net contains an acoustic beacon which the UARS homing system is commanded to seek at the appropriate time. In the event that command communication with the UARS is lost for a preset period of time, the homing system will automatically activate and UARS will begin a search for the beacon. At present power levels, the effective range of the homing system is 2-3 miles under typical arctic noise background conditions. Internally programmed logic, an inertial and depth-sensing guidance system and the command/tracking receivers provide retrieval redundancy. However, in the event of massive power interruption or other catastrophic failure, a further retrieval capability is provided. The submersible has positive buoyancy and will rise to the undersurface of the ice and automatically lower an acoustic beacon to aid an over-the-ice search party. The system includes a beacon location device and appropriate tools for emergency recovery of the vehicle once it is located.

The UARS has about 150 pounds of reserve buoyancy which can be devoted to instrumentation over and above that already installed. There are several ports in the body which allow oceanographic, optical, and acoustic instrumentation to be mounted without major effort. An internal digital recording system has ample capacity for high resolution recording during the run (1000 binary bits per second for 10 hours). After test runs, internally recorded data and externally measured position data are merged on one tape so that spatial-temporal correlation of observed phenomena can be accomplished.

Figures 2.1 through 2.4 show a UARS and some of its major internal components. Figures 2.5 through 2.7 show a tracking buoy, the tracking computer, and a UARS launch, respectively.

Figure 2.1. UARS Unit 1 on Vehicle Handling Dolly

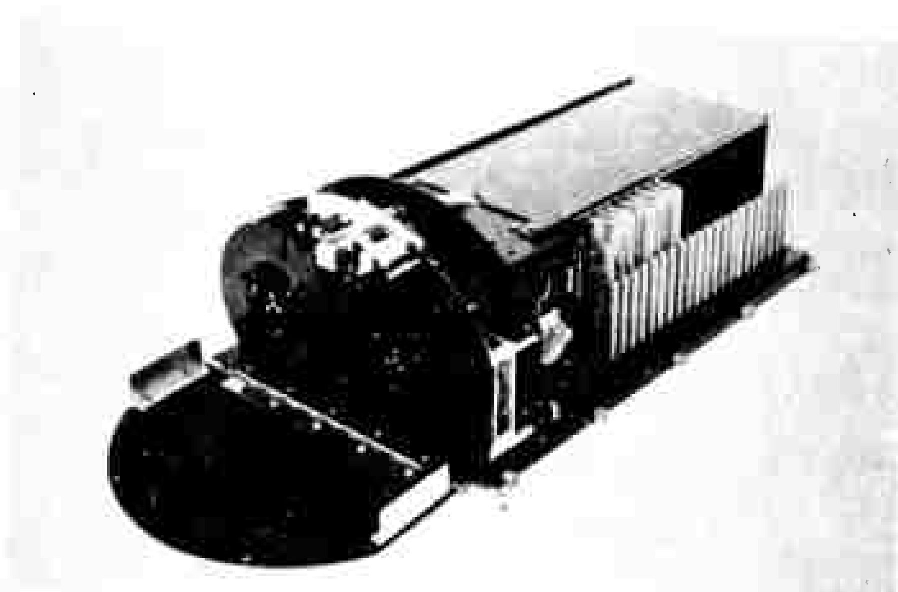


Figure 2.2. UARS Data Chassis with Front Cover Lowered for Tape Reel Removal

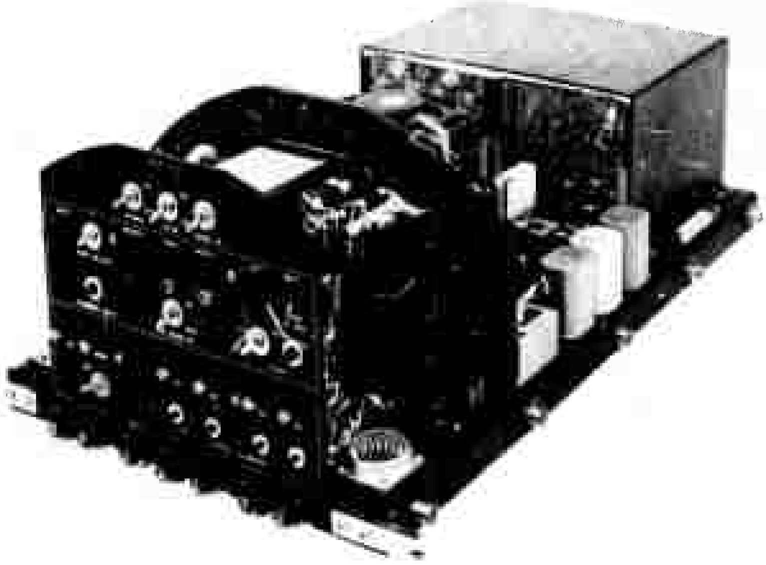


Figure 2.3. UARS Control Chassis

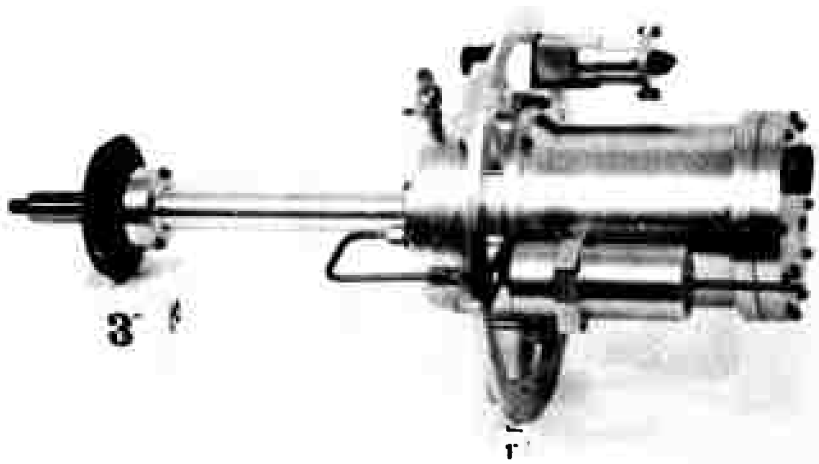


Figure 2.4. UARS Propulsion Unit

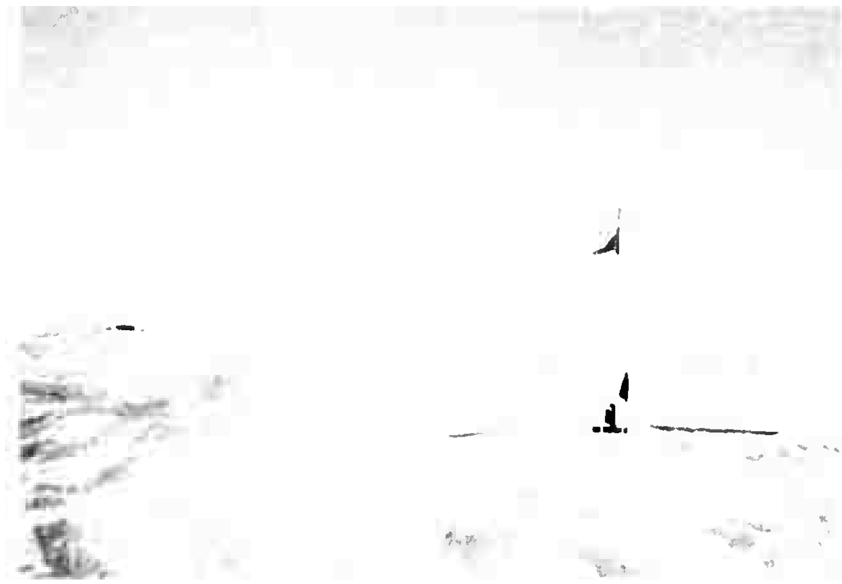


Figure 2.5. Tracking Buoy Installation in Pack Ice of Colby Bay Off Ice Island T-3. Hydrohut for UARS operations can be seen in background.

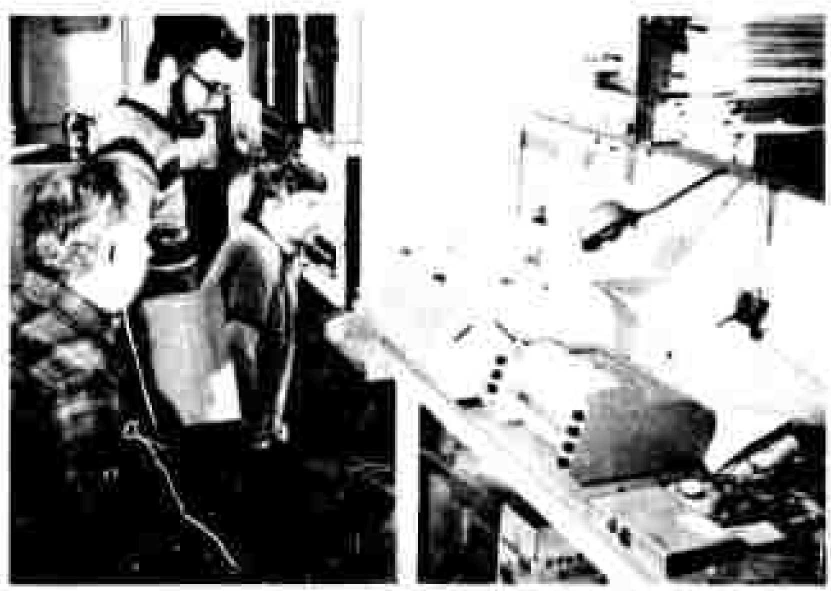


Figure 2.6. UARS Tracking Computer in Operation at T-3 in Spring 1972

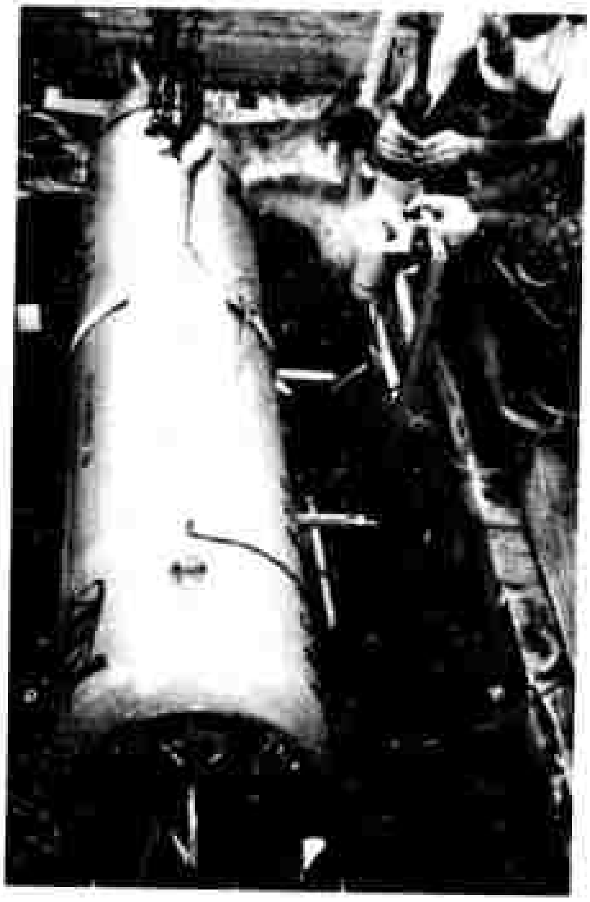


Figure 2.7. UARS Being Lowered on Launch Rack into Hydrohole at T-3 in Spring 1972

3. UARS SYSTEM APPLICATIONS

The UARS development tests in the Arctic were conducted to accomplish two objectives: the first was to complete the development work on the acoustic systems and demonstrate performance of the system; the second was to demonstrate the efficiency and applicability of the system to the important problem of obtaining precise profiles of the underside of arctic ice. The test results discussed in Section 6 clearly demonstrate the attainment of the first objective, and the fine-grain topographic resolution obtained attests to achievement of the second objective. The latter results, coupled with a conventional leveling traverse over the upper ice surface on a selected mile of UARS run, provide the most complete, directly correlated measurements of upper and lower ice surface topography ever made.

These capabilities are important to the defense, transportation, and scientific needs of our country. Submarine commerce in the Arctic depends upon navigational and ice avoidance sonar systems to permit reasonably high speed operations in close proximity to the ice and bottom in the extensive

marginal ice areas. UARS can replace submarines for much of the experimental effort necessary to achieve such systems. For example, the characteristics of ice reverberation and its correlation to the physical size of the ice obstructions must be obtained in order to establish the directionality requirements of the navigational sonar system. It is conceivable that the total development of navigational sonar systems can be done within the dimensional and payload constraints of UARS. The same ice-acoustic parameters that relate to navigational problems apply, of course, to antisubmarine torpedoes which are to be used in the Arctic.

The question of applications can best be addressed by considering the general capabilities of the present design. The UARS design provides for the ready adaptation of a wide variety of special instrumentation. For example, the present vehicle has unused space which could be devoted to additional instrumentation (~150 lb maximum with the present configuration). Several ports are provided for easy hull penetration and the replaceable nose plate is readily adaptable for mounting new sensors.

Hull sections (23 in. length) can be added for increased volume and payload. For special applications, the speed of the vehicle can be increased by motor substitution. The energy required for additional instrumentation, speed or endurance can be provided by adding another battery section. Lengthening the body by one or two sections would increase the drag only slightly and would not appreciably alter the control characteristics.

Conceptually, UARS is not limited to surveys in a local area but can be applied to problems requiring traverses of considerable length. One possible approach would be to utilize the inertial control system to bring the vehicle close enough to an acoustic beacon to be within capture range of the homing system. A series of beacons, sequentially activated, would guide UARS along the traverse. Progressive sequencing of beacons by radio command could be accomplished by using range measurements between the tracking projector on UARS and an RF telemetering hydrophone buoy installed with each beacon. Obviously, the configuration of such an experimental procedure awaits the specific experiment and depends largely upon the logistic problems of setting out the beacon/tracking buoy network.

Similarly, the UARS tracking system (described in Section 4.3) need not be constrained to employment on ice floes. The tracking elements can be mounted on ships or other water-borne platforms, floated freely, or bottom moored at moderate depths in ice-free water.

4. THE OVERALL UARS SYSTEM

4.1 GENERAL

The two major elements of the UARS system are an unmanned submersible which serves as a mobile instrument carrier, and a remote tracking, guidance, and recovery system. The system is perhaps best described by first considering the submersible's characteristics.

The design maximum operating depth of the vehicle is 1500 ft. The initial design provides for operation at a minimum speed of 3 kn. The maximum operating depth of 1500 ft was selected because it is consistent with contemplated experimental programs and because proven technology existed for shell, component, and hull penetration design for that depth.

The design speed of 3 kn was selected because a control system designed for this velocity can, with minor changes, be employed at higher velocities; whereas the reverse does not necessarily follow. This velocity also is compatible with initial experiment objectives in the central Arctic where current velocities are low.

The UARS is capable of running for 10 hr at 3 kn. This matches the data recording and personnel limitations quite well. A separate reserve energy source supports an additional 2 hr of operation at full power for emergency situations.

The nominal distance traveled by UARS in a 10-hr run would be in excess of 30 nautical miles. Simulation studies have indicated that, for experiments where larger traverses are required, a second battery section can be added without appreciably altering the control system performance and only modestly reducing the velocity. This would approximately double the endurance and range of the vehicle.

The energy requirements of UARS are satisfied with silver-zinc secondary batteries. A 14-in. diameter, 24-in. pitch propeller powered by a nominal ¼ hp, pressure equalized (flooded) dc motor is used for propulsion.

The hull diameter is 19 in., a dimension for which hull technology is well established. The weight and volume requirements for all subsystem components (propulsion, energy source, control, field instrumentation, data recording, etc.) and their placement within the vehicle resulted in a final submersible length of ~118 in. and an envelope displacement of 15.5 cubic feet. Since the tailcone is free-flooded, the actual displacement in sea water (1.026 specific gravity) is 910 lb. Approximately 200 lb of ballast is distributed throughout the vehicle, allowing considerable freedom in placing additional instrumentation within, or external to, the hull.

The view of UARS in Figure 4.1 shows the location of the components that are described in the following sections. The submersible itself is described in greater detail in Section 5.

4.2 UARS PROFILING SYSTEM

An immediate objective of the first phase of the UARS program was the development of a system to accurately profile the ice underside. This is accomplished by measuring the elevation of the ice surface above the vehicle at regular intervals. Our performance goal was to establish these elevations to a differential accuracy of 0.25 ft and to identify the corresponding plan view coordinates (derived from tracking information to a repeatable accuracy of 1 ft and a differential accuracy of 0.5 ft. The data rate allows the elevation measurements to be made at about 1-ft intervals in the direction of UARS motion.

The profiler receiving transducer is a spherical, fluid-filled acoustic lens, with three transducers located in the focal surface. Figure 4.2 shows the measured directivity patterns of the individual elements. The individual beam width or the half power points (-3 dB) are about 1° wide at the 500 kHz operating frequency. Beam separation is 6° and side lobes are suppressed 35 dB below the main lobe, so that the response detected from the under-ice surface is associated with that from

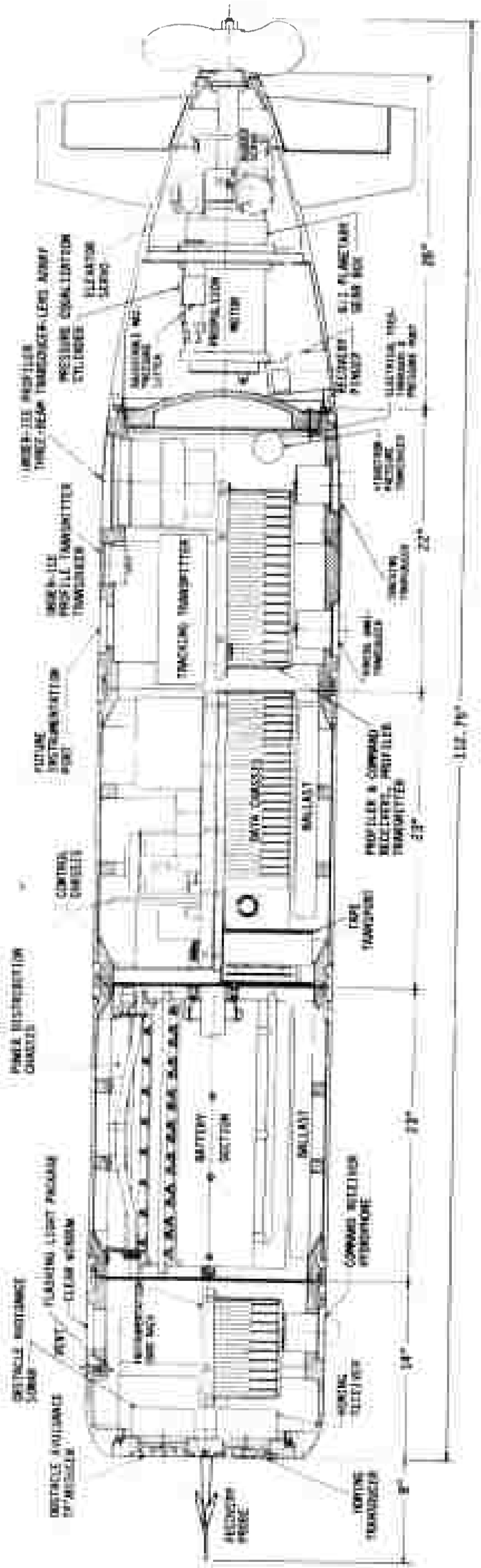


Figure 4.1. Cross-Sectional View of UARS

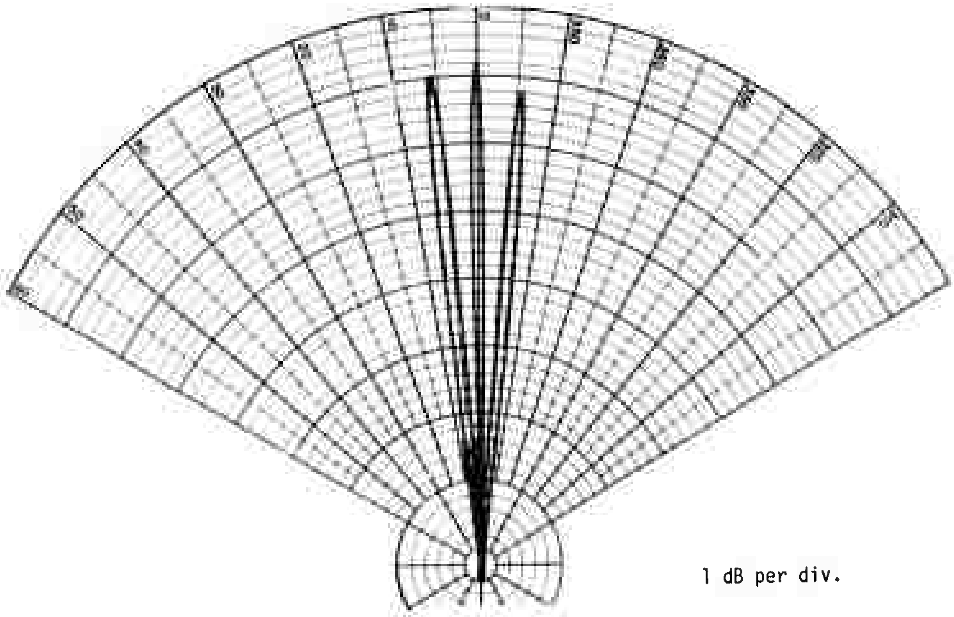


Figure 4.2. Reflectivity Pattern of Three-Beam Transducer Lens System

each main beam direction only. This is an important factor when employing acoustic distance measuring techniques against an ice reflector, since very large variations in reflection coefficients from that surface can be expected. In operation, the profile transmitter transducer, which is located just forward of the multibeam receiver transducer (see Figure 4.1), is pulsed and the refelected signal in the direction of the receiving beams is detected. The overall transit time provides a measurement of slant range. The "fan" of multiple beams is oriented perpendicular to the direction of vehicle motion. When the submersible operates about 50 to 60 ft below the ice, the insonified area associated with the reflected signal is about 1 sq ft. At a vehicle speed of 3 kn and with a recording rate of five data sets per second, essentially continuous surface sampling is achieved.

The geometry of the measurement is shown in Figure 4.3. The elevations Z_{b1}, Z_{b2}, . . . represent successive measurements of ice elevation from lens transducer element b. Z_b is determined by combining the depth of the vehicle (sensed by an internal pressure device) with the slant range D_b, and correcting the measurement for vehicle roll, pitch and yaw. In order to determine corresponding values of X_b and Y_b, corrections must also be applied to the X and Y coordinates of the vehicle tracking transducer to account for beam angle, vehicle roll, pitch and direction of travel. The UARS data system records roll, pitch, D_a, D_b, D_c, depth, and time for later correlation with synchronized, externally sensed and recorded, X and Y coordinates of the vehicle. All data recorded within the vehicle is stored in binary form. The resolution of Z_{b1}, Z_{b2}, . . . is

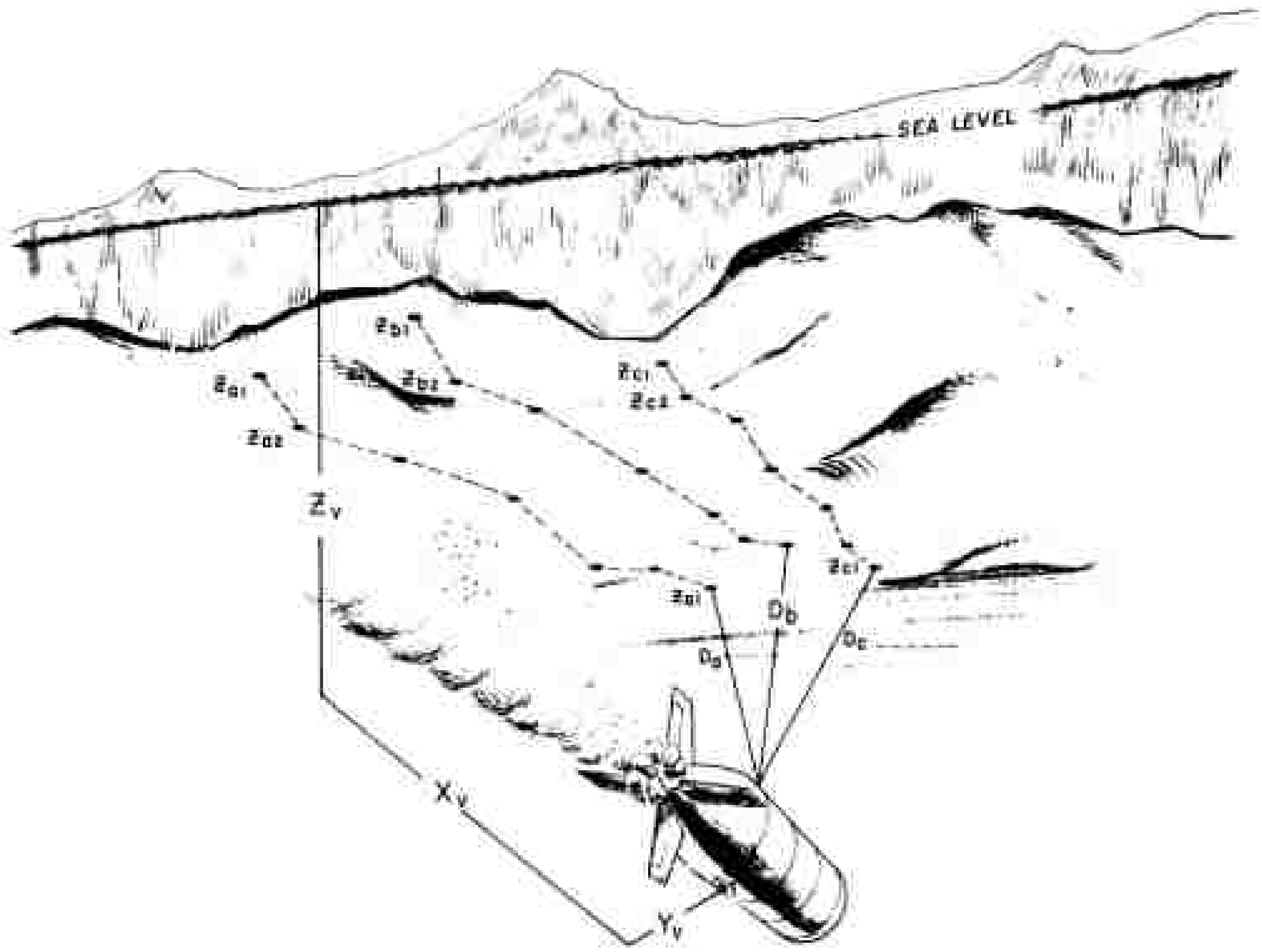


Figure 4.3. Measurement Geometry of UARS Profiling System

approximately 0.3 ft, based upon combined quantitizing limits. In practice, the roll and pitch variation during a run is only fractions of a degree so that differential elevation resolution on a point to point basis is limited by the slant range quantitizing limit of about 0.23 ft.

4.3 TRACKING, COMMAND AND RELATED SYSTEMS

4.3.1 OPERATIONAL REQUIREMENTS

The UARS system has been designed to satisfy the following special operational constraints imposed by the Arctic. The vehicle must

(1) be launched and recovered from a hole in the ice

(2) operate in close proximity to the ice undersurface

(3) have an accurate and reliable tracking system to enable the data to be spatially correlated and to prevent loss beneath the ice canopy

(4) accept control commands from the experiment controller so that anomalies in the data can be investigated more thoroughly as they occur

(5) provide real-time data transmission to the surface command console (to satisfy requirement 4)

(6) be recoverable with a high degree of reliability and minimum personnel risk.

In addition, data from a run must be reduced in the field so that subsequent measurements can be planned and anomalous results can be investigated immediately.

The UARS system design innovations which meet these special demands are detailed below.

4.3.2 LAUNCHING, RECOVERY AND OBSTACLE AVOIDANCE

The submersible is designed for launch and recovery through a hole (~4 x 12 ft rectangle) cut in the ice. After the initial instructions are preset in the vehicle and its internal systems are operating properly, it is lowered into the water to a depth of 50 to 100 ft below the ice, using a launching rack. Acoustic communication and tracking signals are then established. The propulsion motor is started and the UARS is released from the launching rack. The launching rack is a negatively buoyant frame from which the UARS is buoyantly suspended; electro-magnetically operated latch pins on the rack engage lock plates on the UARS to mate the two assemblies.

UARS runs with about 10 lb positive buoyancy. When launched, it rises about 2 ft as it gains enough forward velocity to bring it under full dynamic control. Thereafter, it follows a preset depth program.

Recovery of the vehicle is illustrated in Figure 4.4.* The basic technique involves the use of an acoustic homing system installed in the vehicle. This system responds to a signal transmitted from a homing beacon centered in the capture net. The final phase of homing is conducted at a preset depth so that it is necessary to steer in azimuth only, the net being set at the terminal homing depth. A capture probe mounted in the nose of UARS is firmly meshed with the net upon contact. The motor is then commanded "off", the net and vehicle are raised to the surface, and UARS is hoisted clear of the water.

The homing system employs two closely-spaced hydrophones whose outputs are filtered for response at the beacon frequency and phase-compared to generate azimuthal steering orders. Reflection of the beacon signal from the ice undersurface can cause ambiguous phase relationships, so the

---

*See page 67, Figure 6.2, for latest version of recovery net.

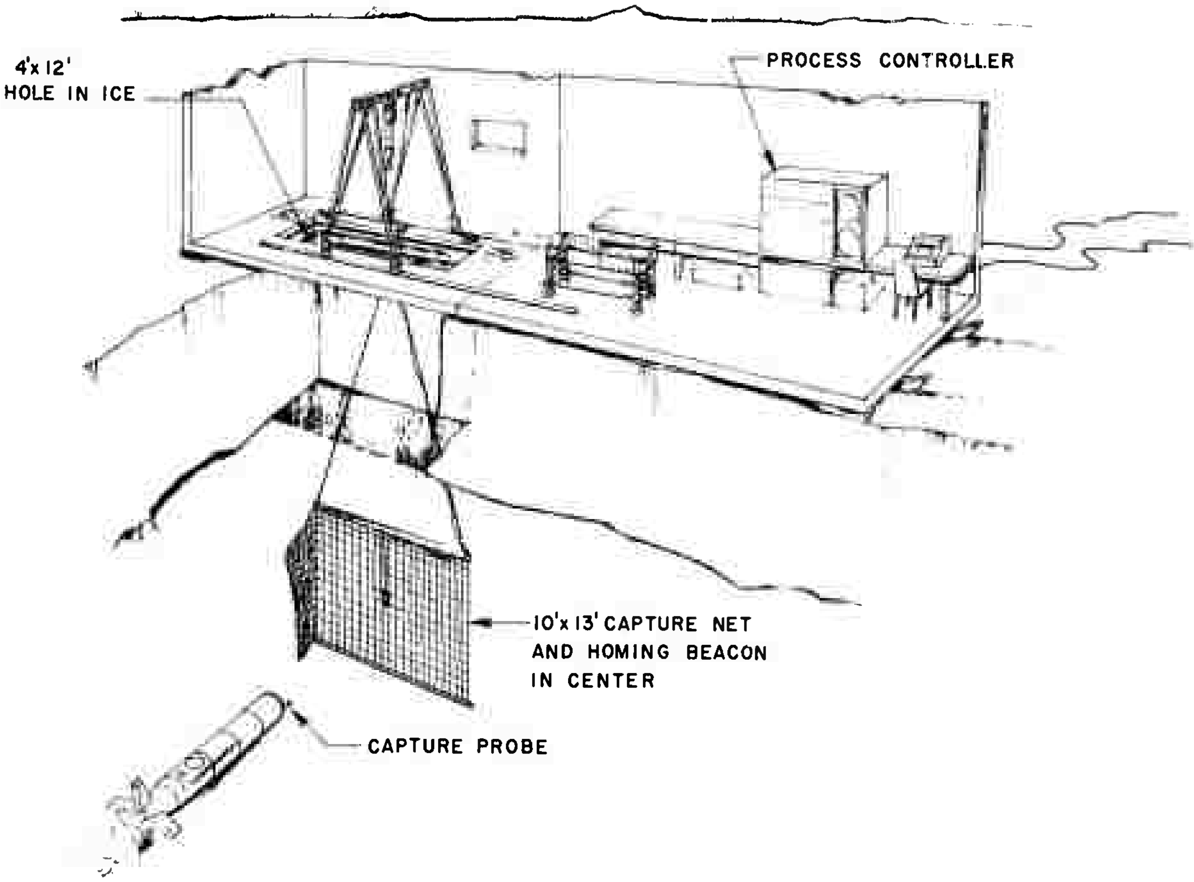


Figure 4.4. UARS Recovery System

homing system includes an interlocking set of logic which must be satisfied in order to cause homing on the direct path pulse only. A simplified flow diagram which describes the logic chain is shown in Figure 4.5. In addition to the bearing-measuring transducers, a sensing hydrophone mounted on the aft cylindrical section of the vehicle is employed. The logic chain requires that the pulse sensed at the steering hydrophones precede the pulse detected at the sensing hydrophone by a fixed time (0.8 msec) which ensures that the detected signal is in the forward sector, ±45° with respect to the vehicle axis. The logic rejects any rate of change of the detected phase imbalance between the steering hydrophones which exceeds the maximum valid vehicle bearing rate with respect to the fixed target beacon. Other requirements ensure that the detected signal has the character of the transmitted signal. These features are necessary to overcome interference effects noted in tests of the basic phase detector system during under-ice tests in the Arctic. Tests in Puget Sound during the winter of 1971 when the vertical sound velocity profile allowed long direct path acoustic propagation, utilized the same acoustic system but with a much simpler logic. Signals in excess of steering threshold requirements were obtained at ranges greater than 3 miles when using an 80 dB CW beacon (28 kHz). During

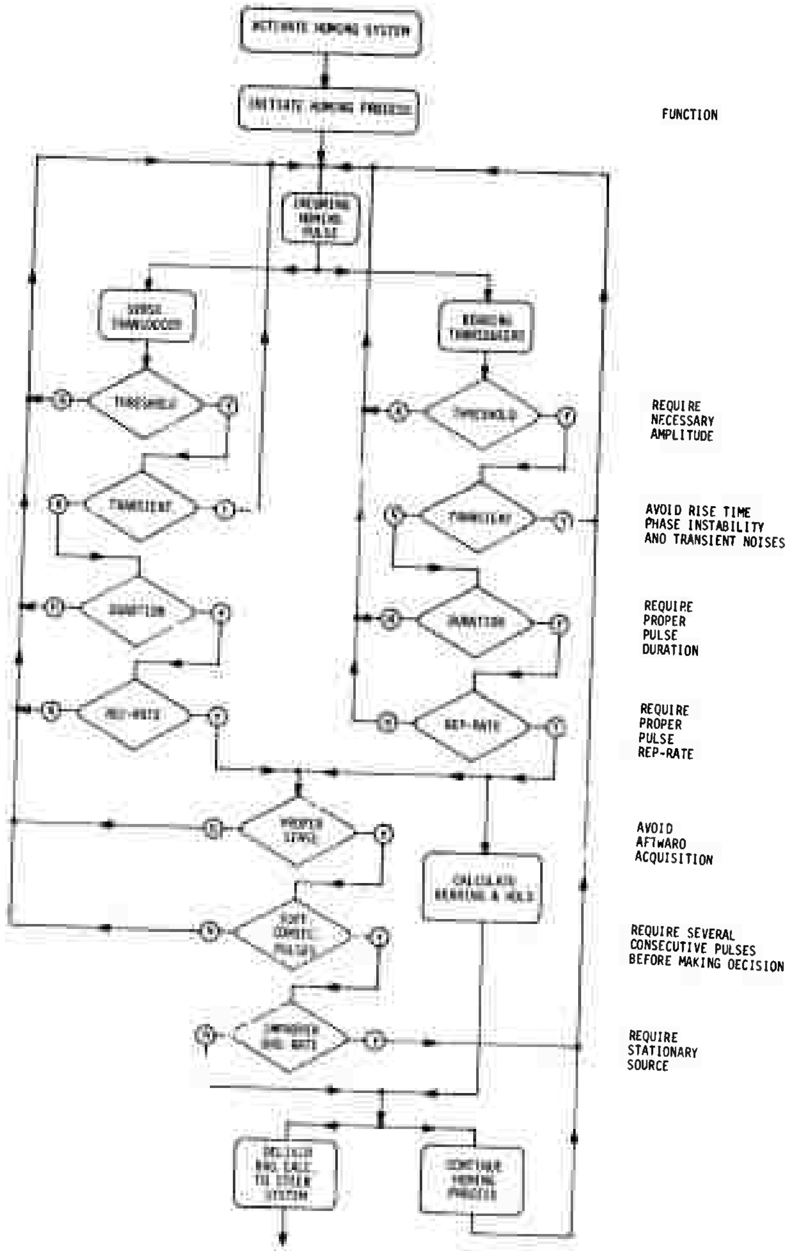


Figure 4.5. Simplified Flow Diagram of Homing Receiver for UARS

the arctic tests in April 1971 an operating range of 2 miles was achieved with the same equipment. The difference in range is almost exactly accounted for by greater absorption losses associated with the lower water temperatures in the Arctic.

To avoid collision with deep pressure ridge keels, the vehicle is equipped with an obstacle avoidance sonar. This system operates at a

frequency of 360 kHz, employing a 200 μsec pulse which is about 1 ft long. Pulse length broadening, an expected characteristic of the return from the ridge keels, is used for pulse validation (fish echoes will be rejected). The high attenuation at this frequency allows a high pulse repetition rate (five pulses per second) so that obstacle avoidance logic can be based on receipt of multiple valid returns. The sonar beam is axially directed and is of sufficient width to encompass the normal pitch oscillations and trim conditions of UARS. When an obstacle is detected, the vehicle dives to a deeper preprogrammed depth. After the obstacle is passed, the vehicle can be commanded to return to the original depth if desired. (The fact that the obstacle avoidance measurement has been made is communicated by the data-telemetering system which is discussed later.)

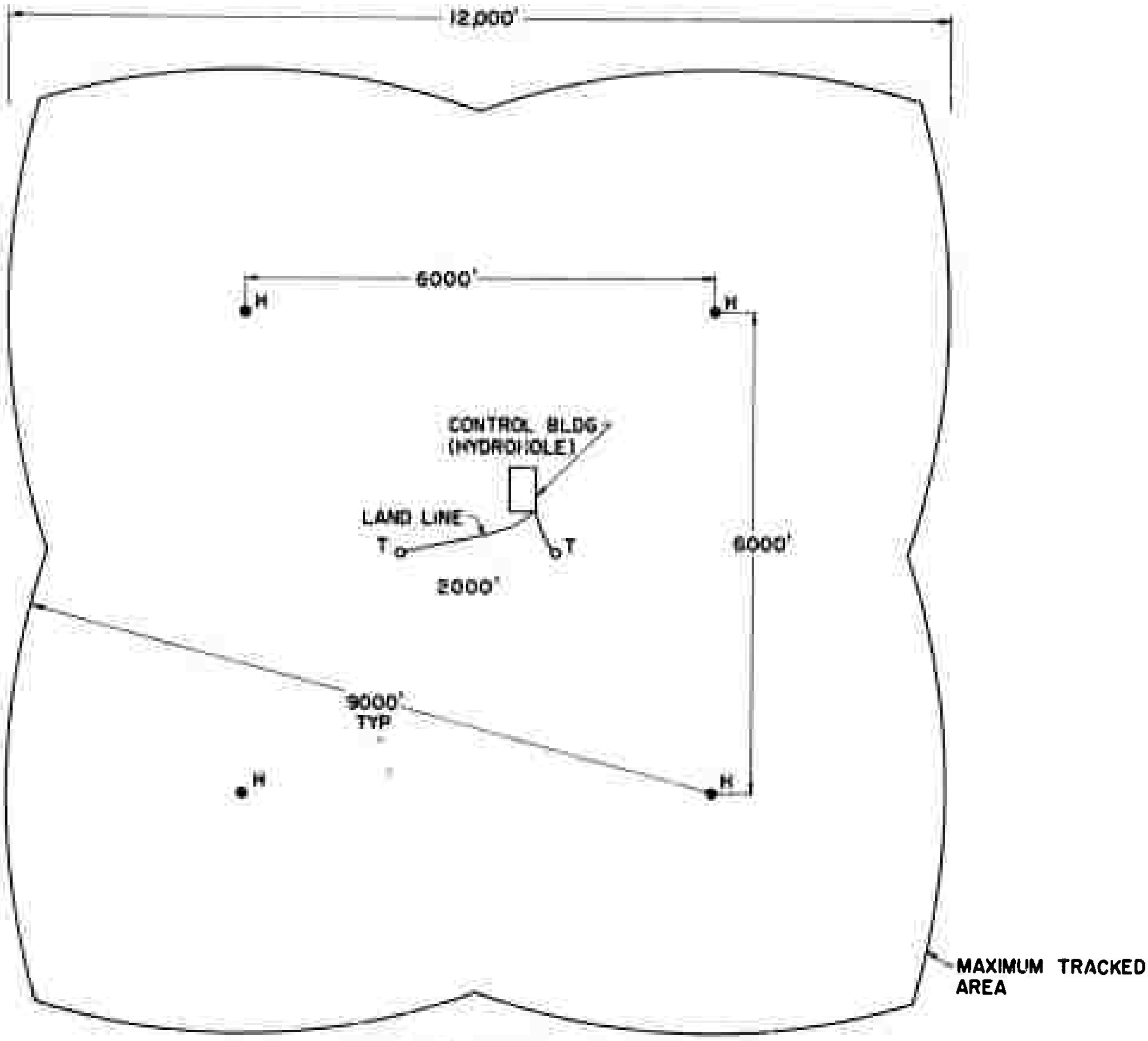
4.3.3 ACOUSTIC TRACKING

A plan view of a typical tracking area arrangement is shown in Figure 4.6. Four hydrophones (labeled H in the figure) are installed through holes in the ice in a square arrangement, perhaps 6000 ft on a side. Two baseline transducers (labeled T) would be located about 2000 ft apart in the center of the square. The origin of the tracking coordinate system and the direction of the coordinate axes are determined arbitrarily by the location of the baseline transducers. The general geometry of the tracking and command/communication system arrangement is shown in Figure 4.7. An acoustic pulse is transmitted from UARS at fixed time intervals of 2 sec. At the same time, a pulse is transmitted from one baseline transducer. The pulses transmitted by the baseline transducer and the submersible are received at hydrophones and relayed by radio to the control building where they are entered into the tracking and data acquisition system. The transit time of the acoustic pulses between the baseline transducers is also monitored at the control building. The command transducer is suspended through the ice in the control building and is at roughly the same depth as the hydrophones.

The hydrophone assembly is shown in Figure 4.8. The hydrophone itself is suspended on a cable from a buoyant container which houses an acoustic receiver and RF telemetry system. The batteries which power the hydrophones are located in close proximity to the sea water to maintain a constant, relatively warm temperature. They can be recharged (or replaced) from the surface. The four hydrophones are suspended at preselected, known depths of 250-300 ft below the ice to reduce signal interference. Interference of direct and reflected signals is discussed in the next section.

Each baseline transducer is weighted and suspended from the ice platform. The reference baseline is taken as the acoustically measured distance between the two transducers. To achieve a reliable, direct acoustic path between these two transducers, they are suspended at known depths, 50 ft or more below the pack ice. A coaxial cable connects each baseline transducer to the control building.

In the UARS acoustic tracking system, a common time base is established by synchronizing very stable clocks at the control building and



H = TRACKING HYDROPHONE, DEPTH ≈ 250 FEET.
T = TRACKING BASELINE TRANSDUCERS, DEPTH ≈ 50 FEET.

Figure 4.6. UARS Tracking System Arrangement

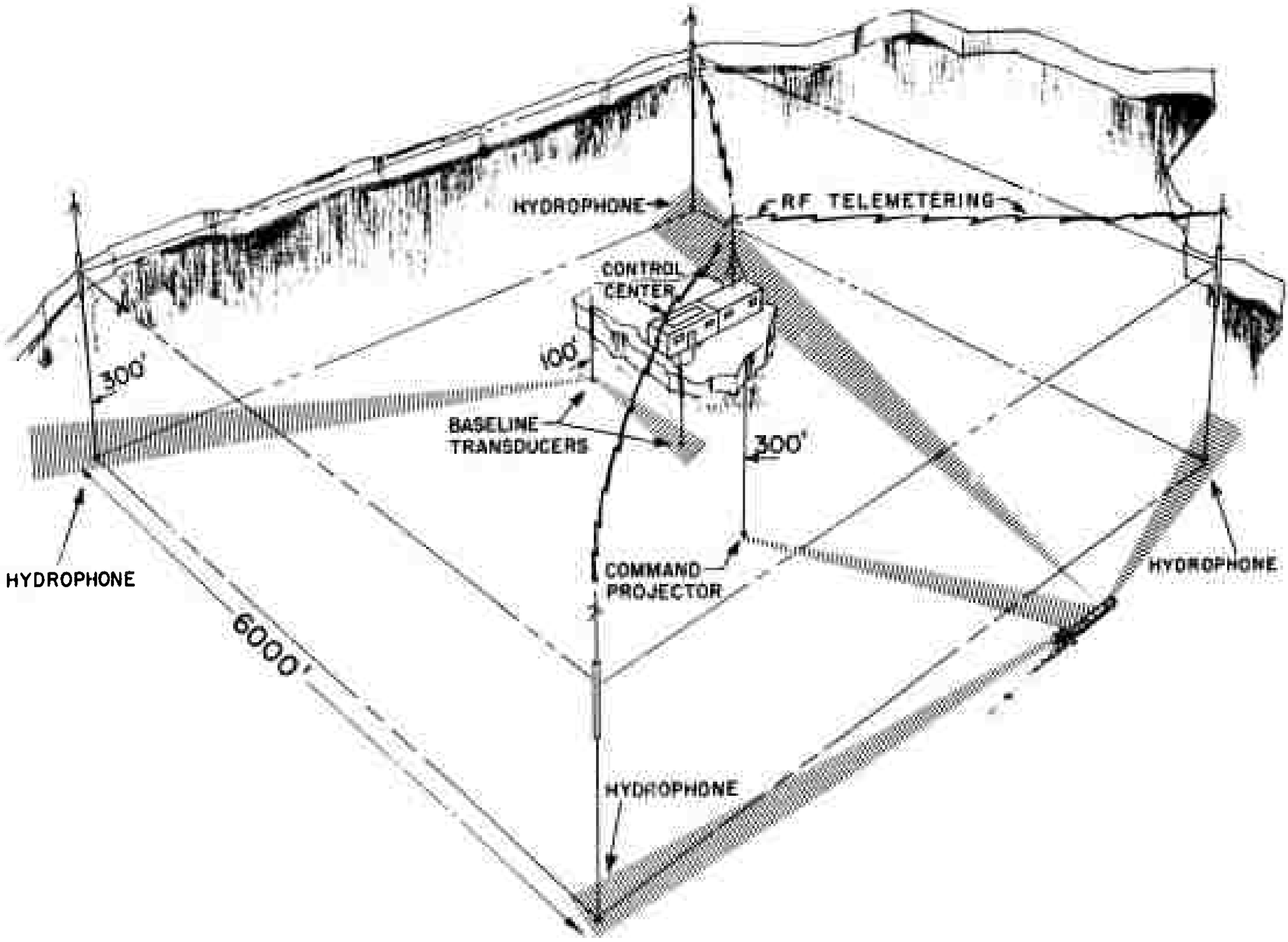


Figure 4.7. Tracking and Command/Communication System Conceptual Layout

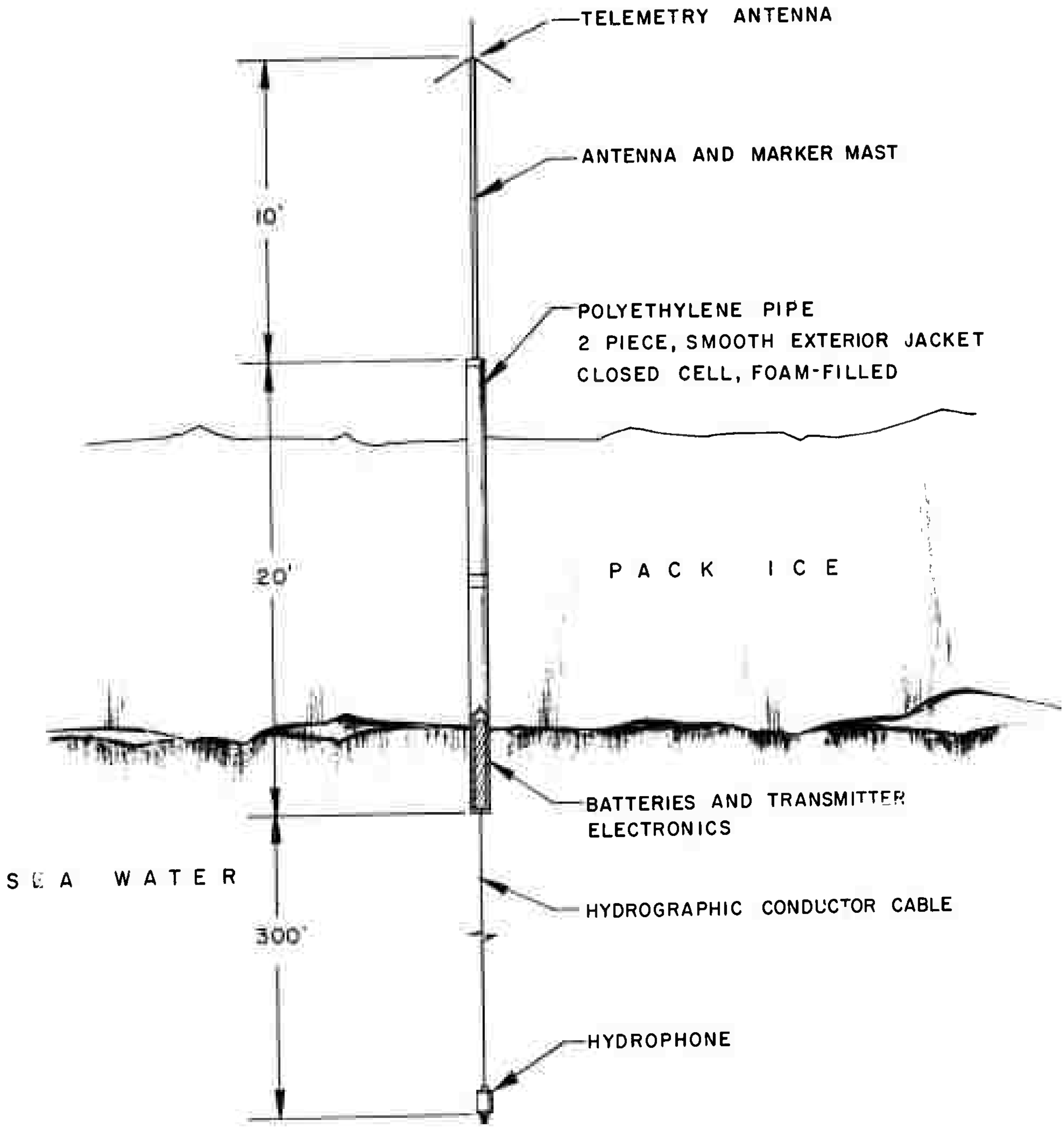


Figure 4.8. Tracking Hydrophone Buoy

within the submersible. All vehicle-recorded data is referred to the clock in the submersible, and all externally recorded data is referred to the clock at the control building. During operational tracking, the vehicle projector emits an acoustic pulse every 2 sec and slant ranges to the hydrophones are determined from velocity-time calculations. The hydrophone positions can be continuously measured acoustically with respect to the transducer baseline so that the frame of reference is always current. Periodic measurement and correction of the sound velocity profile is also made to assure the required tracking accuracy. An analysis of time-series oceanographic data taken at T-3 during 1970 indicates that a biweekly updating of the profile should be adequate for this purpose. Additional measurements made during our 1972 spring operation confirmed this assumption.

4.3.4 COMMUNICATION

In order to control the UARS accurately and to ensure its reliable recovery, an acoustic communication link with the vehicle is employed. The system utilizes a common frequency for command, tracking, and vehicle data transmission. When operating acoustic telemetry near an interface such as the ice-water boundary, one of the principal problems is that a signal reflected from the boundary may be superimposed upon the direct path transmission and interfere with the information content. There are several techniques available to minimize this problem; however, the direct approach, the one we have taken, is to provide a geometry and pulse length which preclude the overlap. In an isovelocity medium, the maximum length pulse that can be received free from interference is approximately

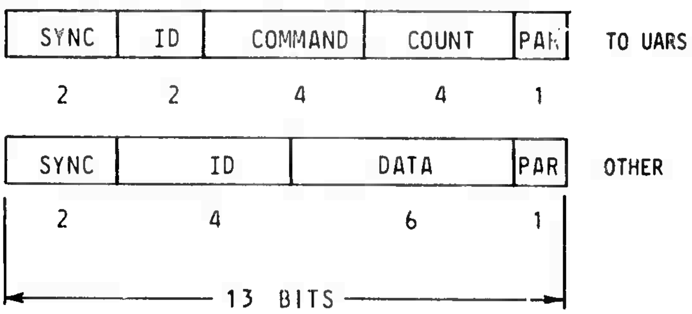
$$\Delta L = \frac{2h_1h_2}{D}$$

where h_1 and h_2 are the depths of the acoustic elements below the reflecting plane, and D is the horizontal separation. One of the acoustic elements (UARS projector) can be as close as 50 ft below the ice. At a range of 6000 ft, and with the other acoustic element about 500 ft deep, there is a 1.8 msec time difference between direct and reflected paths. Correcting this example for the actual sound velocity structure in the central Arctic (as measured at T-3 during Jan-May 1970) one finds a depth of about 300 ft will provide the same clear pulse time.

It was determined that the minimum data transmission requirements would be satisfied by a 10 bit code. Various keying options, their bandwidth constraints and acoustic system interactions were considered before deciding to employ a single-frequency, 100% phase-modulated (180° phase reversal) code. Transmission experiments using water paths in excess of 1 mile established that a minimum of five cycles of the carrier was necessary to reliably establish phase reversal at modest signal-to-noise ratios. At the selected frequency of 50 kHz, a 10 bit code with five cycles defining a bit will require a 1 msec pulse. For practical communication, two additional bits are required for pulse recognition and phase locking and

one for parity. The required overall pulse length is then 1.3 msec. Assuming that the submersible would be traveling at a depth 50 ft below the ice, a hydrophone depth of about 250 ft is adequate to prevent pulse overlap.

The code structure is shown in Figure 4.9. The upper band represents the format of the command code, while the lower band represents all other codes. The first two bits of each code format are used for pulse recognition and receiver phase locking. The next two bits, 00, identify a command message to the vehicle. The type of command is specified in the next four bits, and the magnitude of the command by the four "count" bits. The parity bit validates the message. For example, the four "command" bits may identify any of 16 functions such as "change of course to port" and the four "count" bits may identify any of 16 preselected angular increments. The other codes can include data messages from UAR's acknowledgment of commands, or reports on system performance. Projectors other than the baseline transducers can also be employed for some system applications. A Bottom Navigation Buoy (BONABUOY) could be used, for example, for measuring pack ice drift over the bottom. The codes for identifying the baseline and hydrophone location signals are shown at the bottom of Figure 4.9. The structure of each identification code is such that pulse identification at any receiver is relatively simple.



ID		
0 0		COMMAND TO UARS
0 1 0 0	TRACKING PULSE & PROFILE DATA	FROM UARS
0 1 0 1	STATUS 1	
0 1 1 0	STATUS 2	
0 1 1 1	SPARE	
1 0 0 0	TO BONABUOY	OTHER FIXED REFERENCE
1 0 0 1	FROM BONABUOY	
1 0 1 0	SPARE	
1 0 1 1	SPARE	
1 1 0 0	TRANSDUCER 1	BASELINE AND HYDROPHONE LOCATION
1 1 0 1	TRANSDUCER 2	
1 1 1 0	SPARE	
1 1 1 1	SPARE	

Figure 4.9. Acoustic Communication Binary Code

4.3.5 TRACKING AND DATA ACQUISITION SYSTEM PROCESSOR

A block diagram of the tracking and data acquisition system is shown in Figure 4.10. The acoustic signals received at the four hydrophones are recognized, processed, and transmitted along with hydrophone identification by radio link to the control building. A signal processor recognizes the identification code, strobes the time input from the master timer, and shifts the data to an interface unit which buffers the information until it can be acted upon by the process controller. The process controller reviews the input data from each hydrophone for consistency. If the decoded message is not the same from all hydrophones, the message from each hydrophone is separately printed out for observation; if the messages are in agreement, only one printout of the message is made. The pulse time and unedited data are stored on magnetic tape so that various processing options can be exercised during post-operation data reduction. The process controller performs the arithmetic operations necessary to determine the UARS position corresponding to the received data set. The process controller also regulates the pulsing of the baseline transmitters. The arrival time of the baseline signal pulse, along with known hydrophone and baseline transducer depths and the effective sound velocity, are used by the process controller to determine the locations of the four hydrophones. The separation distance between the baseline transducer is normally quite stable. However, the acoustic transit time between the

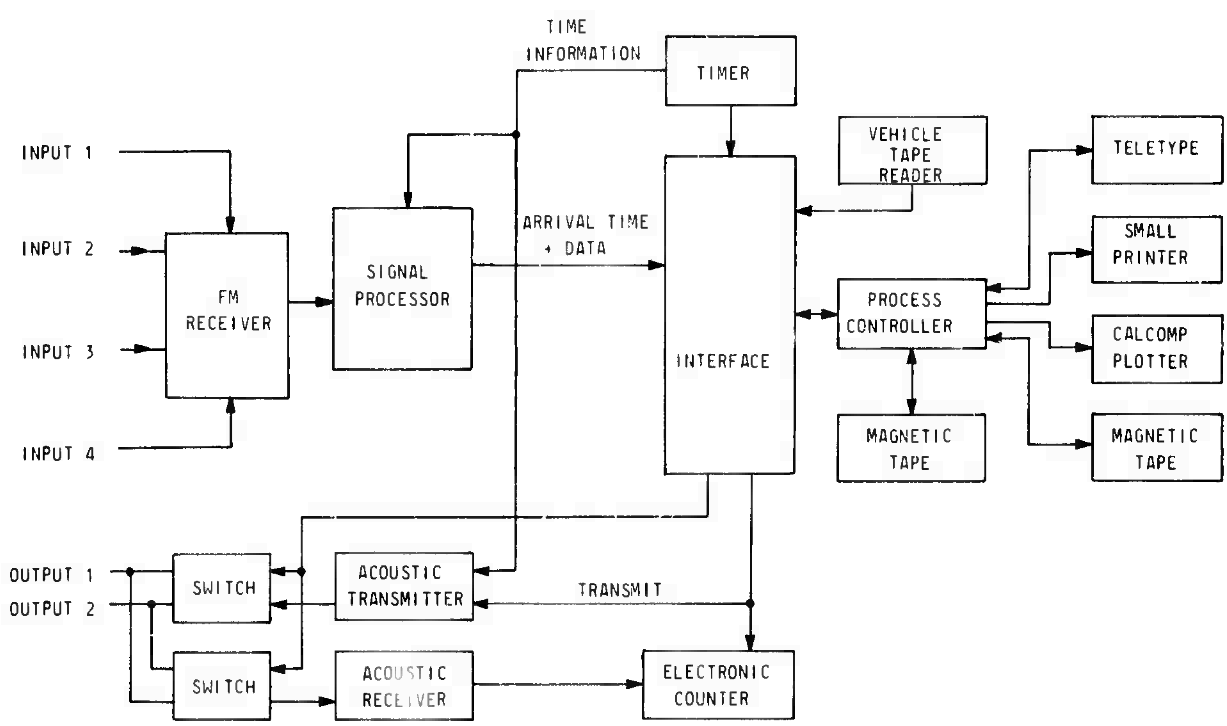


Figure 4.10. Tracking and Data Acquisition System

two elements is monitored on each transmission with a time interval counter. If the baseline distance changes during a vehicle run, this is indicated by a change in acoustic transit time and the new baseline time (or distance) is provided to the tracking system by a keyboard entry.

The acoustic data from UARS includes the operating depth and (in an ice profiling experiment) the nominal distance to the ice undersurface measured by the middle beam of the profiler. This approximate elevation of the ice underside and the corresponding position and time is output by the process controller to a small line printer and a position plotter. Inspection of this output provides the necessary control information to the experimenter.

Commands to the UARS are sent through the command projector. The control commands are entered digitally by means of the teletype keyboard to the computer which digitally generates the acoustic command function. When UARS receives a command, it is acknowledged with a "status" report as provided for in the code structure (see Figure 4.9). This acknowledgment is listed on the printer output.

After completing the run, the UARS internal recording, which is in digital binary format, is first scanned to detect anomalies in the data or vehicle performance. The scanner system consists of a tape reader and data demultiplexer compatible with the UARS tape system, eight digital-to-analog converter channels, and a multichannel strip chart for analog data output. The data can be plotted on the digital plotter when greater detail is required.

After data scanning, the vehicle tape record is transferred to standard computer tape and reformated. The vehicle data is compressed in order to maximize the total number of stored bits; to bring to standard format, additional gaps have to be created to allow word separation. The final output of all field data then will be in an IBM tape format which can be directly used with a standard ½-inch, nine-track tape unit.

After a run, the vehicle data and the timing/communication data (tracking) exist on two separate tapes. All data can be merged on one tape, using the three tape units available within the data acquisition system. This capability allows a significant amount of data to be reduced in the field, and offers experimenters timely information for modifying the remainder of an experiment or planning further experiments.

4.4 FAIL-SAFE LOGIC AND EMERGENCY RECOVERY

4.4.1 FAIL-SAFE LOGIC

Reliable operation of the UARS is achieved by careful component selection, system design, and redundancy. For example, the main battery and the reserve battery when connected in parallel are diode blocked to prevent discharge of the reserve into the main battery. This arrangement allows full use of all available stored energy in an emergency.

The high probability of recovery in the event of a subsystem failure is ensured by providing a combination of built-in logic, operator command options, homing technique alternatives, and practical recovery options should the vehicle come up under the ice.

The vehicle is not released from its launching rack until the propulsion motor is operating, tracking is established, and the acoustic command link is operative. If the vehicle tracking signal is lost near the extremities of the tracking area, the operator will command a vehicle course reversal to return it to the area of stronger tracking signal strength. If the UARS fails to receive a command communication from the controller for a period exceeding 5 minutes, the vehicle course is automatically reversed and an alert code transmitted to the controller. The UARS is programmed to remain on this course for 12 minutes. If communication with the controller is established during this period, the run can be continued normally. If not, the logic will send the vehicle down to a deep preset depth, cause it to circle in a spiral of increasing radius, and activate the homing system. The experiment controller will turn on the homing beacon whenever he fails to receive tracking communication signals from the UARS, when he observes uncommanded course changes in the vehicle which result from internal logic decisions, or when the communication code from UARS fails to acknowledge receipt of a command. After a 1-hour spiral search without beacon acquisition, the propulsion and all other internal systems except the tracking transmitter are shut down. Thereafter, the vehicle will rise to the ice underside because of its slight positive buoyancy. If the tracking information is being received by the hydrophones, the vehicle coordinates can be determined and emergency recovery procedures initiated.

If the homing system fails, but the tracking and communication systems are operable, the operator can command the vehicle back to the recovery hole and attempt to strike the capture net with the aid of tracking data and visual observations. (In clear arctic waters, the flashing strobe light in UARS is quite visible through several hundred feet of water.)

If UARS dives below the maximum preset limit, the propulsion motor is automatically turned off. Power is returned when the vehicle rises above the depth limit. The operator can attempt to correct the condition by commanding a different depth. If that fails, an attempt can be made to steer the UARS to the desired recovery area, although progress may be quite slow because of the on-off motor operation.

4.4.2 EMERGENCY RECOVERY

In the event that a failure results in propulsion power shut-off, the vehicle will float up to the undersurface of the ice unless water leakage into the vehicle was the cause of failure. In the latter case, the vehicle will sink and be lost since no reasonable recovery technique exists.

Vehicle location is the basic problem in emergency recovery. Installed in the afterbody of the UARS is a recovery pinger. The pinger operates from self-contained batteries and is turned on upon immersion in water. It is secured in place with a soluble link which will release after 14 hours submergence and allow the pinger to drop several hundred feet below the vehicle on a line tether to achieve a more reliable acoustic path for detection.

The location of the pinger is established by triangulation. Several holes would be drilled through the ice with an ice auger and a directional hydrophone receiver used to establish the direction to the pinger. An accuracy in the vehicle position of better than 50 ft should be achievable with three or four observations, once acoustic contact has been made. Locating the vehicle by this process may be time consuming, therefore the pinger is designed to operate for about 21 days.

After the vehicle has been located, a 30-inch square hole will be cut through the ice. A diver, tethered to the surface, will locate the vehicle and attach a lifting line to a nose hook. A small weight will be attached to the tail so that the vehicle hangs nose up at the recovery hole. Man power can be used to bring the UARS to the surface, but a hoist would be used to lift the vehicle free of the water and load it on a sled for transportation back to the hydrohole hut. The hoist normally kept at the hydrohole would be used for this operation.

A variation of this procedure is applicable if the UARS position under the ice can be determined from its acoustic tracking projector which should continue to operate until battery exhaustion. The tracking signal can be used for location, similar to the pinger system described above. A trial hole would be drilled in the vicinity, a tracking projector lowered through the hole and its coordinates determined acoustically. From the locations of two or more such holes, the relative position of the UARS could be established within a few feet before making the recovery hole.

A technique for making launch and emergency recovery hydroholes, as well as for coring out instrumentation frozen into the ice, has been developed and tested in the arctic environment. This technique is discussed in Section 6.1.

5. DESIGN OF THE UNMANNED ARCTIC RESEARCH SUBMERSIBLE (UARS)

5.1 GENERAL

The general design characteristics for the Unmanned Arctic Research Submersible (UARS) are given in Table 5.1. The bases for these design values are discussed in the following sections which describe the hull design and the various component systems of the vehicle.

Table 5.1. UARS Design Specifications

Maximum operating depth	1500 ft
Speed	3 kn
Displacement	~900 lb
Overall length	~10 ft
Diameter	19 in.
Propulsion	¼ hp dc motor (pressure equalized)
Power sources	
Main battery	Silver-zinc, 260 A-h at 24 V
Reserve battery	Silver-zinc, 60 A-h at 24 V
Endurance (based on load of 10 A for propulsion motor and 15 A for instrumentation and control systems)	12-hr maximum
Operational net buoyancy	+10 lb

5.2 PRESSURE HULL DESIGN AND COMPONENT LAYOUT

Figure 5.1 is a cross-section view of the vehicle with the major hull design features and component layout. Some blocks indicate envelope volumes of the particular component rather than a pictorial view.

The pressure hull is designed for a maximum operating depth of 1500 ft with a calculated crush depth of 2800 ft. In the design of pressure hulls, internal volume, shape, construction material, depth capability, weight and payload capability are factors involved in a trade-off analysis. In this case, the hull size was determined principally by the space requirements of the components to be carried in the hull. A cylindrical hull shape was used to obtain a relatively high pressure capability with a low drag profile. The material selection (aluminum and Fiberglas), fabrication techniques, and joint design between sections are based on a previous hull design of proven depth capability. A payload requirement was determined on the basis of known component weights for power, propulsion, vehicle control, and presently planned instrumentation -- with an allowance made for future instrumentation.

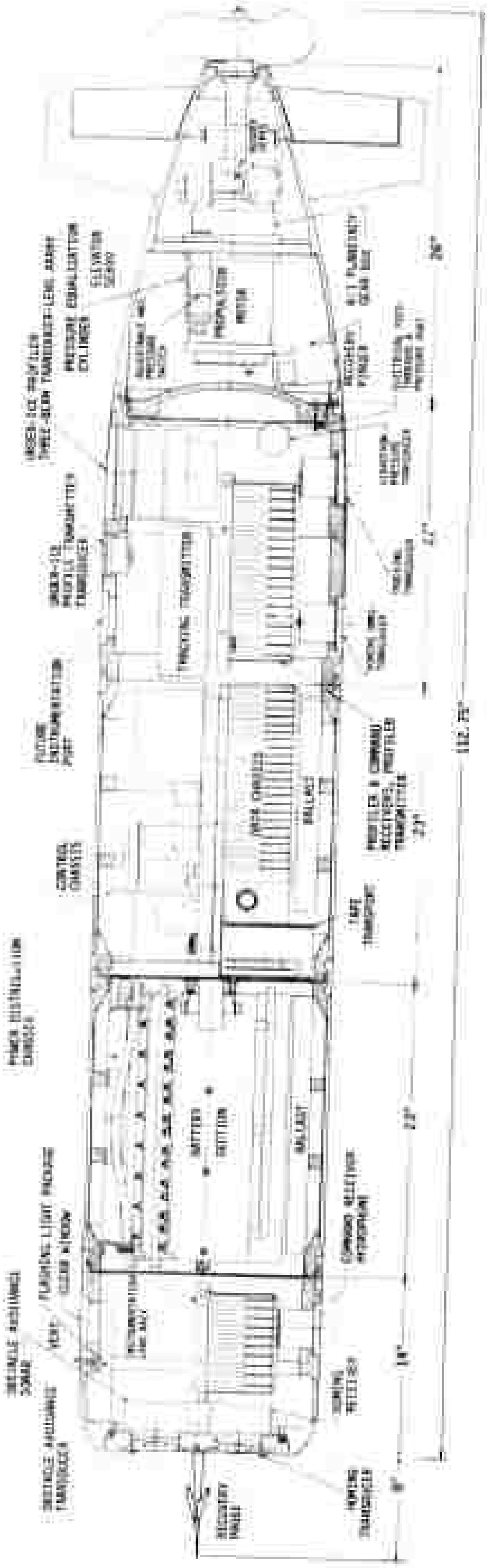


Figure 5.1. Cross-Sectional View of UARS

The vehicle comprises five small sections: a pressure hull consisting of four sections, and a flooded tailcone section. The vehicle can be broken down into individual sections for shipment to and from the test site. The size and weight of each section is compatible with light aircraft transport capability.

The sections containing transducer penetrations, the joint rings and all ribs are made of 6061-T6 aluminum. The shells of the two sections aft of the nose section and a large portion of the tailcone are made of filament-wound reinforced plastic.

The battery section is located forward of the vehicle center of gravity to counteract the large "nose up" pitching moment from the free flooded afterbody. Ballast below the center of buoyancy is used to partially counteract the torque of the propulsion motor.

The tracking transmitter transducer is located directly below the profiler multibeam transducer-lens array so that the tracking positions can be easily correlated with the profiler data. The command receiver transducer (hydrophone) is located in the nose section. "Pop-out" transducer units are used in these locations to protect them from damage during handling of the vehicle. The transducer element in these units is mounted on a spring-loaded pressure-actuated piston which extends the transducer from the vehicle hull when the external water pressure exceeds approximately 6 psi.

The obstacle avoidance sonar transducer, the homing receiver transducer, and an instrument for the measurement of sea water temperature are mounted on a removable nose plate. This nose plate can easily be modified with further watertight electrical connector penetrations and additional instrumentation at minimum cost.

Spare transducer mounting ports on the top side of the nose and aft sections of the pressure hull have been included as alternate locations for the command and tracking transducers when making runs with the vehicle at depths very much greater than that of the tracking range transducers.

Normal servicing between runs is accomplished by separating the vehicle at the joint just aft of the battery section. This provides access to the following: the battery, for charging or replacement with a fully charged battery; the data chassis, for changing magnetic data tapes and setting new run depths; the control chassis; and the power control panel on the front of this chassis which contains the switches for starting the vehicle instrument calibration, initial setting of gyro heading, and control system checkout. The data chassis, control chassis, and battery are mounted on slides within rails fixed to the hull so that they can be easily removed for servicing.

5.3 PROPULSION UNIT

A vehicle speed of 3 knots was chosen to match the initial research mission requirements. Drag calculations were made for a vehicle with UARS's dimensions and shape operating at this speed. The propulsion motor

horsepower requirement was calculated using these drag values and estimates of propeller and gear train efficiency. The value of drag is dependent on the precise vehicle shape and appendages and the angle of attack at which it travels through the water. A range of values was obtained from a minimum of 0.1 hp to a maximum of 0.25 hp. The actual measured horsepower output during level run with the vehicle was 0.15 hp at a speed of 3.7 kn.

A conventional approach to propulsion system arrangement is precluded by power losses in rotating shaft seals across the pressure differential that exists between the interior of the vehicle and ambient depth, and by the catastrophic results of leakage upon a vehicle which is nearly neutrally buoyant. The approach taken was to place the motor in a thin-walled container filled with a pressure-equalized, non-conducting fluid. A secondary seal separates the fluid and sea water; the fluid pressure is maintained slightly higher than ambient so that sea water will not enter the motor in the event of minor leakage or seal wear. This arrangement unfortunately creates trim problems in that placing the motor, gear box, and equalization cylinder aft of the pressure hull in a non-buoyant tailcone produces a tail-heavy condition. The feasibility of extending the pressure hull further aft while retaining the "canned motor" approach by enclosing it within an internal pressure vessel (itself contained within the pressure hull) was investigated as a possible means of reducing the trim problem without increasing vehicle length. This attempt was not fruitful, but it clearly showed the advantages, from a reliability and maintainability viewpoint, of the present arrangement shown in Figure 5.1.

Both ac and dc motors were investigated to determine the most suitable unit for this application. An ac motor would require a solid state dc-to-ac inverter to provide the drive power and special "start up" circuitry. The ac motors exhibit good speed regulation and do not have the commutation problems inherent in dc motors (particularly in flooded motor operation). On the other hand, the overall efficiency of the inverter-motor combination is low, the cost is high, and the weight and space requirements are much greater than for a dc motor of equivalent horsepower.

The dc propulsion motors used in the vehicles have permanent magnet fields and are rated by the manufacturer to deliver 1/4 hp (in air) at an output speed of 1200 rpm with a 24 volt nominal input. Permanent magnet-type motors were chosen in preference to the wound field type because of their higher efficiency over a wide range of output loads and because they are smaller in size and weight than an equivalent unit of the latter type.

Tests were conducted to determine the efficiency of the motors when running submerged in Stoddard's cleaning solvent (the fluid in which they operate when mounted on the vehicle). Test results show an efficiency of approximately 70% (see Figure 5.2) over the output range of 0.1 to 0.25 hp while running in the solvent, as compared to 73% over the same range for "in air" operation.

A 6:1 planetary gear reduction unit is used; its housing provides a flange for attaching the motor enclosure and pressure equalization chamber to the tailcone.

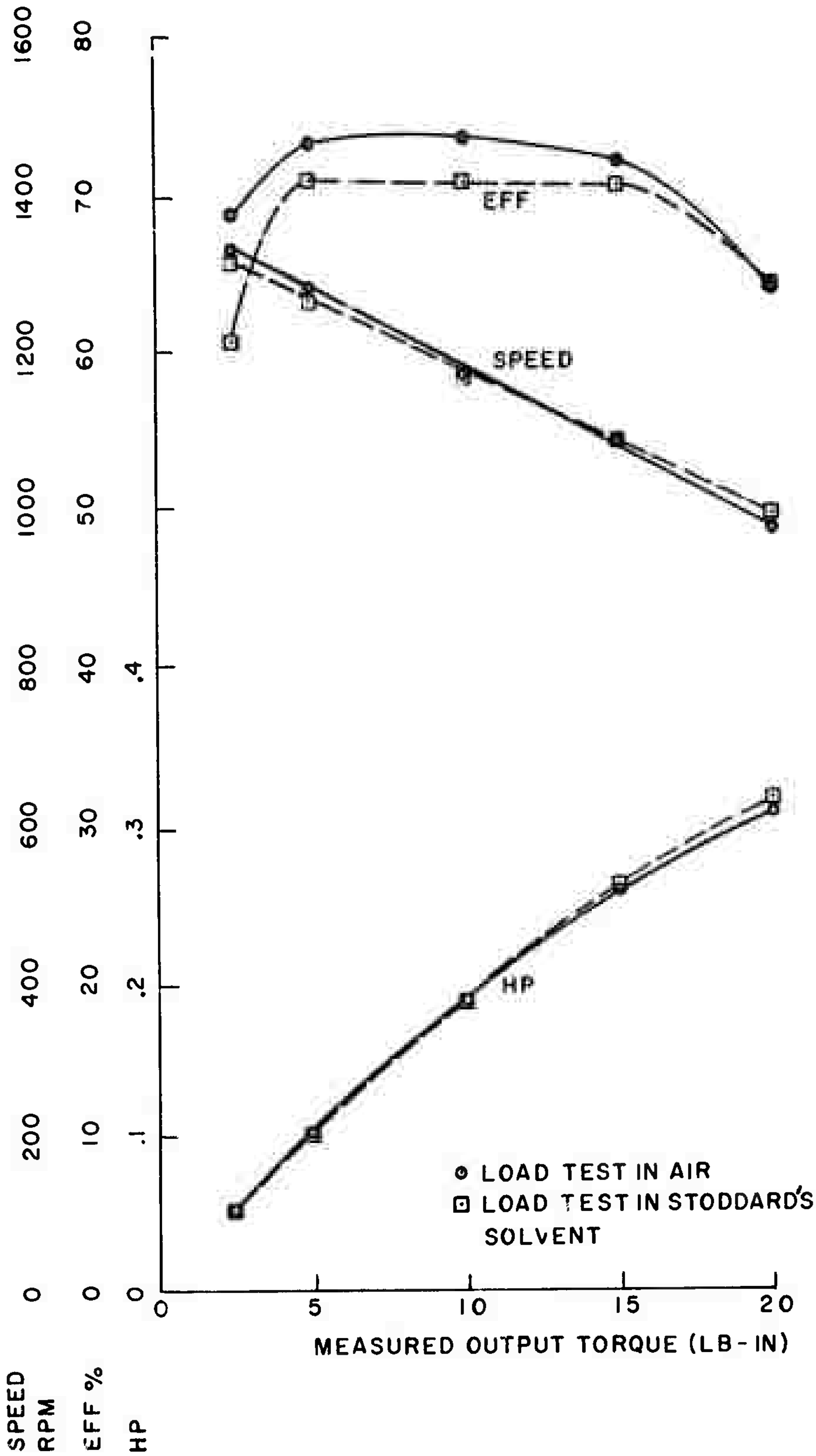


Figure 5.2. UARS Propulsion Motor Characteristics

The propeller is three-bladed, 24 in. pitch, 14 in. diameter, with the hub cone angle conforming to the tailcone shape. The efficiency of the propeller at the 3-knot speed was investigated and calculated to be approximately 70%. This is very near the theoretical limit implicit in the vehicle drag, propeller diameter, and velocity relationship.

5.4 BATTERY SUPPLY

Various types of batteries for the vehicle were investigated. A run time of 10 hours was set as a minimum requirement based on planned vehicle missions. A nominal battery voltage of 24 V was set to conform to the propulsion motor requirement, and the total battery load (propulsion motor plus instrumentation) was estimated to be approximately 25 A. These requirements formed the basis for the comparison, shown in Table 5.2, of the three most suitable battery types.

Lead-acid batteries were given consideration because of their low cost, but were rejected because: (1) they have very poor discharge characteristics, (2) special precautions must be taken against spillage and acid fumes, (3) gassing during charge and discharge presents an explosion hazard, (4) they are subject to freezing at arctic temperatures (particularly so, if in a partially discharged condition), and (5) their weight and volume are excessive.

Silver-zinc batteries were selected because their high energy density matches the requirement for the vehicle to be as small and lightweight as possible to facilitate portability and handling.

For increased reliability the vehicle carries two battery supplies: a 260 A-h main battery and a 60 A-h reserve battery. The main battery provides the normal 10-hour run capability. Battery-monitoring circuits are included in the design so that should the main battery fail, the reserve battery will be switched on automatically. It provides slightly more than 2 hours of run time to enable the vehicle to return to the recovery hole.

5.5 POWER CONVERTERS AND POWER CONTROL

The vehicle uses solid state dc-to-dc converters to supply closely regulated +15, +5, and -15 V from the 24 V battery supply. A 24 Vdc to 115 V, 400 Hz sine wave solid state inverter having good frequency stability and regulation is also included to supply power to the directional gyro and the tape transport drive motor.

If the main battery voltage drops below 20 V, the battery monitoring circuits function as follows:

(1) The reserve battery is switched in parallel with the main battery (each battery pack contains series diodes to prevent discharge of one battery into the other).

Table 5.2. Batteries Considered for UARS

Type (Particular Cell Units Considered)	Weight (lb)	Volume (cubic ft)	Initial Cost	Recycling Capability & Storage Life	Low Temp. Storage & Operating Capability	Comments
	Note: Weight, volume and cost given are approximate values based on 10-hour run with 24 V battery, 25 A load (battery packaging not included)					
Silver-Zinc (Yardney LR130)	136	1.0	$4600	80–100 cycles (Deep Discharges) Approx. 2 years	Storage: −55°F to +100°F Operational: −10°F to +165°F. Approx. 5% loss in capacity at 0°C.	Excellent discharge characteristics. Very low internal resistance. Rugged, leakproof and spillproof.
Silver-Cadmium (Yardney YS140)	220	1.7	$7100	200–300 cycles (Deep Discharges) Approx. 3 years	Storage: −55°F to +100°F Operational: −10°F to +165°F. Approx. 10% loss in capacity at 0°C.	Excellent Discharge Characteristics. Very low internal resistance. Rugged, leakproof and spillproof.
Nickle-Cadmium (Sonotone 81H120)	530	3.9	$6200	>1000 cycles (Deep Discharges) Indefinite but very long life depending on use.	Storage: −65°F to +165°F Operational: −65°F to +165°F. Approx. 10% loss in capacity when discharged at 0°C.	Good discharge characteristics. Low internal resistance. Rugged and spillproof.

(2) An alarm code is acoustically telemetered to the tracking station via the tracking pulse to alert the tracking operator to turn on the homing beacon if it is not already on.

(3) A timing circuit is started which, after 5 minutes, activates the homing mode in the vehicle.

Although the reserve battery is not used during a normal run, its voltage is also monitored and if its voltage drops below 20 V, a separate alarm code is sent to the tracking station, and the timing circuit which activates the homing mode after 5 minutes is started.

The vehicle contains both a minimum and a maximum pressure switch. The maximum pressure switch serves as a fail-safe device for the depth control system, and its function will be discussed in that section. The minimum pressure switch actuates at a fixed pressure corresponding to a depth of about 25 ft. Its function is to conserve battery power in the event that the vehicle is unable to return to the recovery hole and comes up under the ice or in a lead. This switch is bypassed by relay contacts until the vehicle has been lowered, or dives, below 25 ft. Actuation of the pressure switch energizes the bypass relay which will hold itself on through holding contacts. When the pressure switch deactivates, power is disconnected by means of control relays from all components except those necessary for operation of the tracking transmitter. This transmitter can then serve, along with the recovery pinger, as an acoustic source for locating the vehicle's position under the ice.

A motor control circuit is provided which will start or stop the motor on the basis of inputs from the acoustic command system. If the vehicle loses commands, goes into a spiral search for the homing signal, and does not pick up either commands or the homing signal over a period of 1 hour, the circuit automatically shuts off the motor.

Reed switches, which can be magnetically activated from outside the pressure hull, serve the following purposes:

(1) to turn off power to all components within the vehicle (this is important if it becomes necessary to send a diver down through the hole to disentangle the vehicle from the recovery net)

(2) to enable the propulsion motor, steering actuators, and tape transport motor just prior to launch

(3) to set gyro heading.

The power control system is designed to conserve power during warmup and checkout of the various systems prior to launch by applying power only to those systems necessary for the checkout.

5.6 DEPTH CONTROL

A simplified block diagram of the depth control system for the UARS is shown in Figure 5.3. The system is designed for an operational range of 0 to 1500 ft with a depth stability on the order of ±1 ft during a full-length horizontal run.

The pressure sensor selected for the depth control system is a Vibrotron* pressure transducer having a sine wave output with frequency proportional to depth. These units are well-suited for this application because of their low hysteresis, high repeatability, and high resolution. Although the standard units exhibit good temperature stability, the transducers used in the vehicles are enclosed in a temperature-controlled oven because of the wide range of operational temperatures encountered and the depth accuracy desired. The sine wave output is desirable because it is relatively insensitive to noise at the output and is easy to convert to digital form.

A digital depth reference is used (see Ref. 2 for a detailed description of a similar system) to provide a highly stable reference and a convenient means of setting the four preset running depths (i.e., a set of

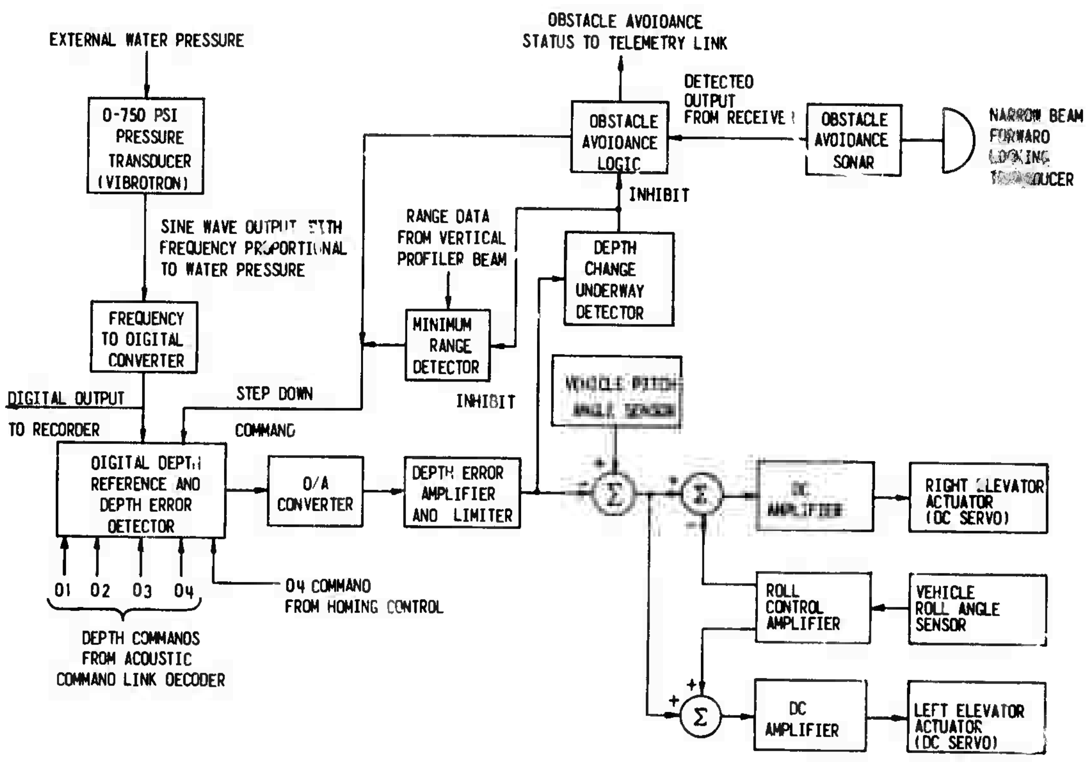


Figure 5.3. Simplified Block Diagram of UARS Depth Control

---
*®

switches representing a binary number for each depth). The submersible can be commanded to any one of four preset depths as well as to step up or down in small increments from any of the preset depths by means of the acoustic command link from the tracking station. Inputs from the obstacle avoidance sonar or the under-ice profiler will send the vehicle to the next lower preset depth each time a step-down command is received from either of the two units. A command to go to D4 (the deepest depth setting) is initiated by the homing control circuitry whenever the vehicle starts a homing search.

The digital output from the depth error detector is converted to an analog voltage, amplified, limited (the limiter sets the dive and climb angles), and summed with the pitch angle sensor output. The pitch angle input acts as a depth rate feedback in the depth control loop (see Ref. 3). The output from the summation point is further amplified and fed to the right and left linear elevator actuators.

An analog computer simulation of the depth control system was used to determine vehicle depth stability and response characteristics to step changes in depth assuming a vehicle speed of 3 kn. At the time of these computer runs, the vehicle shape and dimensions were not firm and differed slightly from the final design; however, the results obtained are representative of the actual system performance (see Section 6.2). The first runs were used to determine the depth control amplifier(s) gain requirements for satisfactory vehicle response to step changes in depth. Simulation runs were made with a depth control configuration using solenoid-actuated elevators, and for the linear elevator actuator configuration shown. Although the pitch oscillations inherent in the solenoid actuator configuration are small (approximately 1° peak-to-peak), they could produce undesirable variations in the under-ice profile data. These oscillations do not occur with a linear actuator, and such a unit is incorporated in the present vehicle.

Another factor which became apparent in the simulation runs was the necessity to limit the net positive buoyancy. With the preliminary body coefficients, the negative angle-of-attack (nose down) required to offset a net positive buoyancy of +20 lb is about 6° at 3 kn as compared to 2° at 6 kn. This angle can be reduced to about 2° at the lower speed by decreasing the net positive buoyancy to +10 lb and increasing the elevator control surface area (as was done in the final design) by a factor of two over that used in the initial simulation. It is desirable to keep the angle-of-attack small because of the rapid increase in drag with angle-of-attack.

The obstacle avoidance sonar is included here as a component of the depth control system since its principal function is to increase vehicle depth to avoid ice keels. The planned operating depth for obtaining the under-ice profile data is 50 ft, and ice keels can extend below this depth. The transducer for the sonar is mounted on the nose of the vehicle with a beam width of 4° between -3 dB points at an operating frequency of 360 kHz. The center of the beam is aligned with the vehicle center line and since

the vehicle has a negative angle-of-attack of approximately 2° during normal level run, the center of the beam is directed downward from the horizontal by the same small angle. Thus, keels extending far below vehicle operating depth will be detected at maximum range while keels only slightly below vehicle depth will be detected at shorter ranges. Preliminary tests with a breadboard model of the obstacle avoidance sonar indicated that a detection range of greater than 300 ft can be expected on deep keels (those 50 ft or more below vehicle depth) provided the angle of incidence between the sonar beam and the ice surface of the keel is less than 50°. Keels having a greater angle of incidence with the beam, or extending to shallower depths, will be detected at proportionately shorter ranges. These detection ranges are considered more than sufficient to permit the vehicle to dive through several depth ranges (assuming 50-ft spacings between D1, D2, and D3) to avoid even the deeper keels which may be present in the arctic basin (see Ref. 4).

A block diagram of the obstacle avoidance sonar is shown in Figure 5.4. The sonar operates at the data rate frequency of five samples/sec giving a maximum unambiguous range of 500 ft. A pulse length of 200 μsec is used which corresponds to an in-water path length of about 1 ft. To discriminate against fish, seals, etc., the detector requires pulse elongation of approximately 5 pulse widths (2.5 ft in range) before a valid return is recognized. Since ice keels will, in general, be sloping, an extended return is expected.

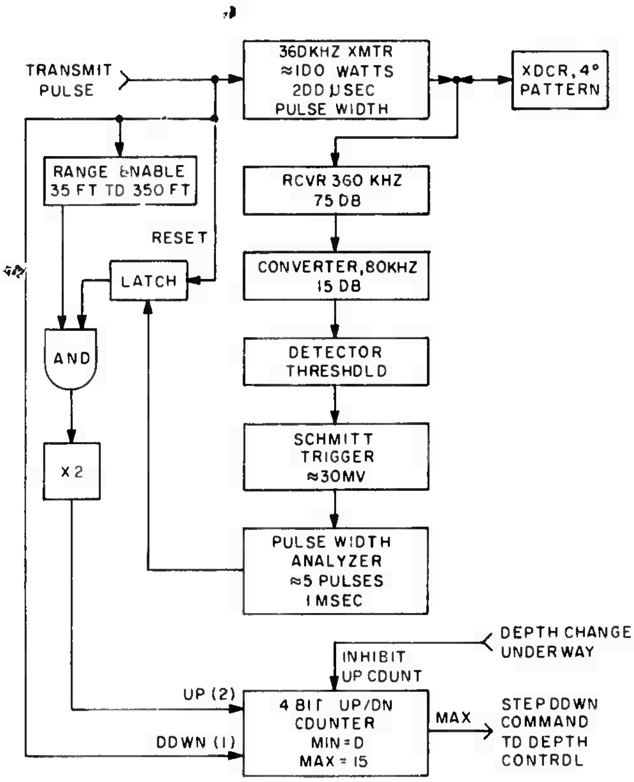


Figure 5.4. Block Diagram of Obstacle Avoidance Sonar for UARS

A school of fish can also produce an extended return, so a running count is made of the valid returns. These returns cause an up-down counter to count up for two counts. A latch prevents acceptance of more than one valid return per sampling period. Each transmit pulse causes a down count of 1 unit, and also resets the latch. With a low valid return rate (50% or less) the average counter reading is near zero. As the valid returns increase in pulse-to-pulse reception rate, the counter output climbs toward its maximum of 15. When the maximum is reached, an avoidance signal is generated.

When a depth change is underway, the counter is inhibited from up-counting, so that an avoidance signal will not be generated during a change to a new level. This requires attention from the tracking operator, who must monitor profiler data (via the acoustic telemetry link) before commanding a shallower run depth to ensure that the vehicle does not climb into the ice canopy. When a depth change is completed, 14 consecutive valid pulses will be required to generate an avoidance signal; this is approximately 14 ft of vehicle travel.

An adjustable maximum pressure switch is used as a fail-safe device for the depth control system. This unit is set before each run to actuate at a depth slightly greater than the maximum depth at which the vehicle is expected to operate during that run. If the depth control system fails and the vehicle attempts to dive below the actuation pressure, the motor will be shut off by actuation of the switch and the vehicle will float toward the surface. The motor will restart when the vehicle rises above the deactuation pressure of the switch. The vehicle would presumably again dive to the actuation pressure and the cycle would be repeated. Each time the propulsion motor shuts down an alert code is sent to the tracking operator. This start-stop sequence should be readily apparent to the tracking operator. If the problem is an incorrect setting in one of the preset depths, this can be corrected by commanding a new run depth. If this fails to correct the problem, the vehicle can be guided to the recovery hole by commanding appropriate headings, even though its progress would be impeded by the start-stop sequence.

5.7 ROLL CONTROL

In the original vehicle design, proper roll attitude and stability during a run were to be obtained by judicious location of weight (i.e., principally the batteries and lead ballast) within the vehicle. Basically the intent was to locate the c.g. of the vehicle as far below the vehicle center line as physically possible to achieve maximum roll stability and to offset the c.g. to the starboard so as to counteract the output torque from the propulsion motor. While satisfactory roll stability could have been obtained in this manner, the corresponding increase in pitch stability would have restricted the maximum dive and climb angles to approximately ±20°, compared to the desired angles of ±45°. It is very difficult to obtain a consistent near-zero roll angle by offset trim weights alone, since the propulsion motor output torque is not constant but varies in accordance with the drag forces on the vehicle which, in turn, vary with

vehicle speed and configuration. A small decrease in vehicle speed normally occurs during a long run because of the decrease in voltage as the battery discharges, and changes in vehicle configuration are likely to occur between runs by the addition or removal of sensor packages external to the pressure hull. Thus, changes in roll angle could be expected both during a run and from one run to another.

With the utilization of linear actuators to operate the vehicle control surfaces, it became possible, by utilization of two actuators on the elevator control surfaces, to add dynamic roll control to the vehicle. The two actuators are driven in opposite directions in response to outputs from a roll angle sensor mounted in the vehicle (see Figure 5.3). For example, a roll angle to the right produces a down elevator angle on the right surface and an up elevator angle on the left (assuming that inputs from the depth control to the dc amplifiers driving the elevator actuators are zero). With the vehicle underway, this produces a differential lift force on the two elevator surfaces and consequently a torque which rolls the vehicle in a direction (to the left for the example given) to reduce the sensed roll angle. With a continuous disturbing torque such as that produced by the propulsion motor, a residual roll angle will occur. This roll angle can be minimized by balancing the major part of the motor torque with fixed offset weights and setting the gain of the roll control loop to as large a value as possible without producing roll instability.

With the dynamic roll control incorporated, it has been possible to more evenly distribute the ballast weight above and below the center line of the vehicle, placing the c.g. at a point such that the desired 45° dive and climb angles are obtained.

5.8 HEADING AND HOMING CONTROL

Strong reliance is placed on the heading control system to bring the vehicle back to the hole for recovery at the end of a run. This is true for normal runs as well as runs that have been prematurely terminated by low battery voltage or loss of command signals.

A simplified block diagram of the heading control system is shown in Figure 5.5. The primary heading reference during a run is a self-leveling directional gyro. These gyros were originally manufactured by Sperry Gyroscope Co. as part of their C-4 Gyrosyn Compass system for aircraft. They are overhauled, and modified to provide a commutator type output. The modification also includes the addition of a stepping motor and associated drive for stepping the commutator in 3° increments in either a clockwise or counterclockwise direction. Drift rate of the gyro is specified by Sperry as 0 ±8°/hour at a latitude of 42°N and 25°C. For this application, the fixed precession rate to compensate for earth's rotation is adjusted at the latitude of the experiment.

The initial gyro heading is set before each launch. Heading changes during a run are commanded through the acoustic link from the tracking station. To terminate a normal run, the vehicle is first commanded to the heading of the recovery hole. A "start homing" command is sent when

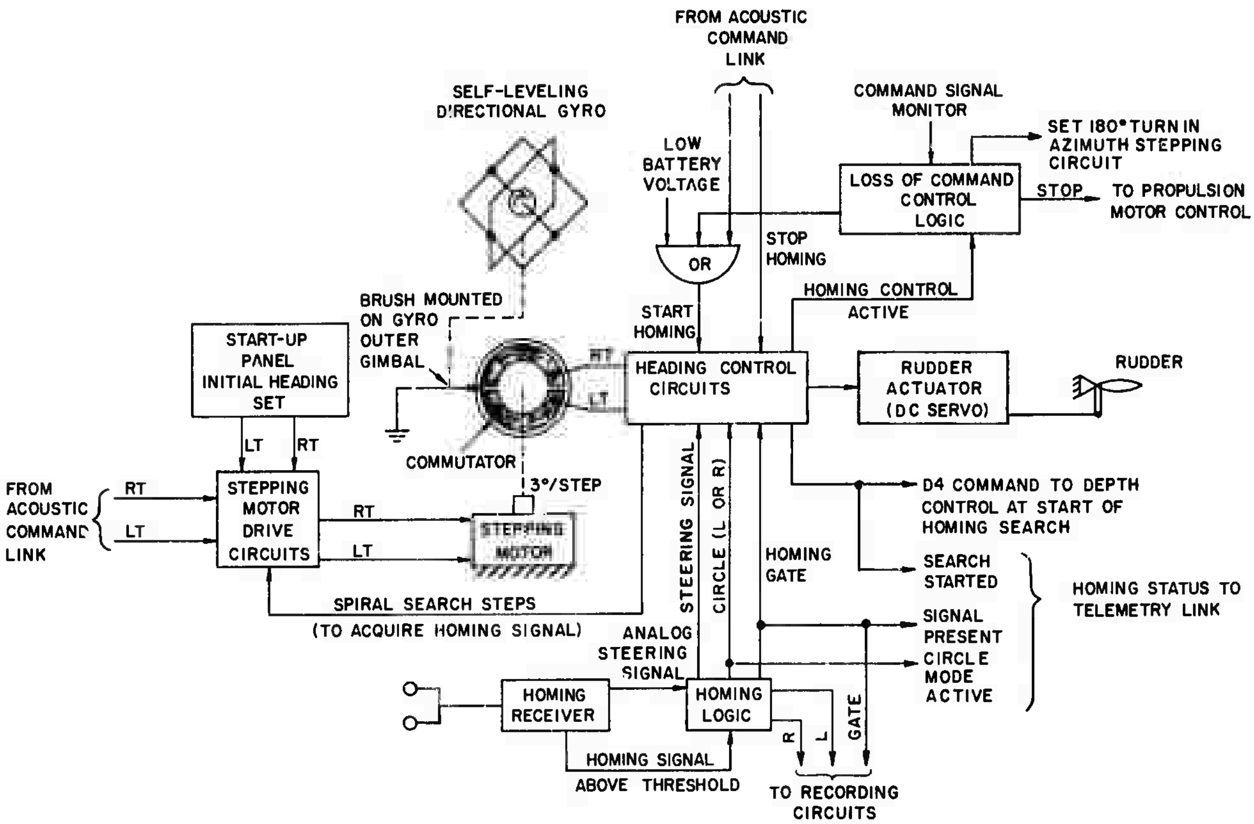


Figure 5.5. Simplified Block Diagram of Heading Control for UARS

it is observed via the acoustic telemetry link (modulation on the tracking pulse) that the homing signal is above the threshold level. The heading control circuits then switch control of the rudder drive circuits to the output of the homing receiver. "Stop homing" can be commanded by acoustic link at any time and heading control then reverts to the directional gyro. Thus, if the homing control malfunctions, guidance to the recovery hole can be attempted with the normal command system.

If a loss of homing signal occurs while the vehicle is in the homing mode, the homing logic allows the submersible to continue on the same path for 30 sec (approximately 150 ft) and then activates either a continuous full right or left rudder (direction of turn can be preset with a switch before the run). The vehicle will then circle until one of the following occurs:

(1) the homing signal is reacquired, at which time the heading control again reverts to the homing receiver

(2) the vehicle is commanded to stop homing, and control reverts to the gyro

(3) the motor stops, either by command or because of loss of commands for a 1-hour period, and the vehicle floats up to the ice.

This sequence ensures the vehicle of another look at the homing beacon in the recovery net if it should happen to miss on the first approach. The intercept angle is changed by approximately 45° on each succeeding pass, as illustrated in Figure 5.6, so that a miss because of a low intercept angle will be corrected on the following pass.

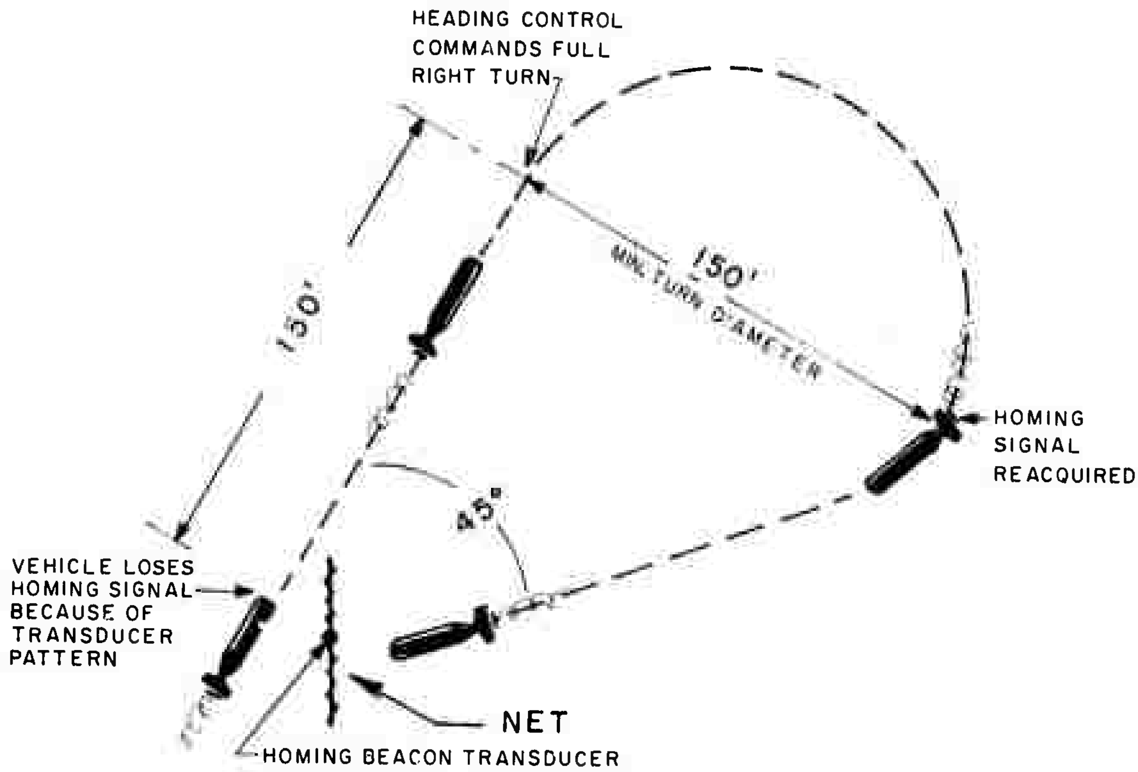


Figure 5.6. Illustration of Vehicle Trajectory After Missing Net Because of Low Intercept Angle

Since navigational control during a run requires receipt of periodic heading changes through the acoustic command link, a failure to receive such commands must be detected by the internal vehicle control system and appropriate action taken to bring the vehicle either back to the recovery hole or to a position where command control is again acquired. To implement this fail-safe logic, an operational requirement is placed on the command system such that commands must be received by the submersible at intervals of less than 5 minutes. These may be redundant commands such as commanding the vehicle to go to depth D1 when the vehicle is already at that depth. If the vehicle does not receive a command for a period of 5 minutes, a "loss of command" sensing circuit actuates a 180° turn in the azimuth stepping circuits which reverses the vehicle course for a period of 10 minutes. This should place the vehicle in the vicinity of where

the last valid command was received. If commands are still not obtained, a failure in one of the command link components is assumed and a homing search mode is activated which, in turn, does the following:

(1) activates an alert code to be acoustically telemetered to the tracking station

(2) sends a D4 command to the depth control

(3) sends steps to the gyro commutator stepping motor at a rate which decreases with time to put the vehicle in a spiral search pattern

(4) switches heading control to the homing receiver output when the homing gate is positive, indicating satisfactory homing signals are being achieved

(5) if homing control is achieved, it resets the timer which shuts down the motor after loss of commands for a 1-hour period.

The purpose of sending the vehicle to its lowest run depth (D4) at the start of the spiral search is to reduce refraction and reflection effects on the homing and command signals.

Low battery voltage signals (discussed in the power control section) activate the homing search mode in the same manner as described above for the loss of command signals.

The UARS homing system makes use of the signal physics of a sonar pulse from a fixed beacon, sensed from a platform moving through a field of stationary but directional acoustic reflectors, to identify the correct beacon direction. A block diagram of the homing receiver is shown in Figure 5.7.

The signal from the homing beacon consists of a pulse-modulated 28 kHz carrier. The pulse rate is adjustable but is normally set for 3 pulses per second (pps); the pulse duration is 4 msec. The homing system is designed to accept any rate between 2 to 5 pps. The power output from the beacon is adjustable from 600 W for far range to 1 W for near range. The amplitude is reduced as the vehicle approaches the beacon since a high level source is not required at short ranges and lowering the amplitude reduces or eliminates reception of ice-reflected pulses above threshold.

Inputs to the homing receiver electronics come from three hydrophones mounted on the vehicle. Two cylindrical PZT hydrophones are located on the nose and spaced 3/8 λ (at 28 kHz) from each other. This spacing precludes a phase ambiguity (which could cause reverse steering). They are referred to as the bearing hydrophones since a phase comparison of the homing signals received at these two transducers provides the basic bearing information used to guide the vehicle toward the homing beacon. They

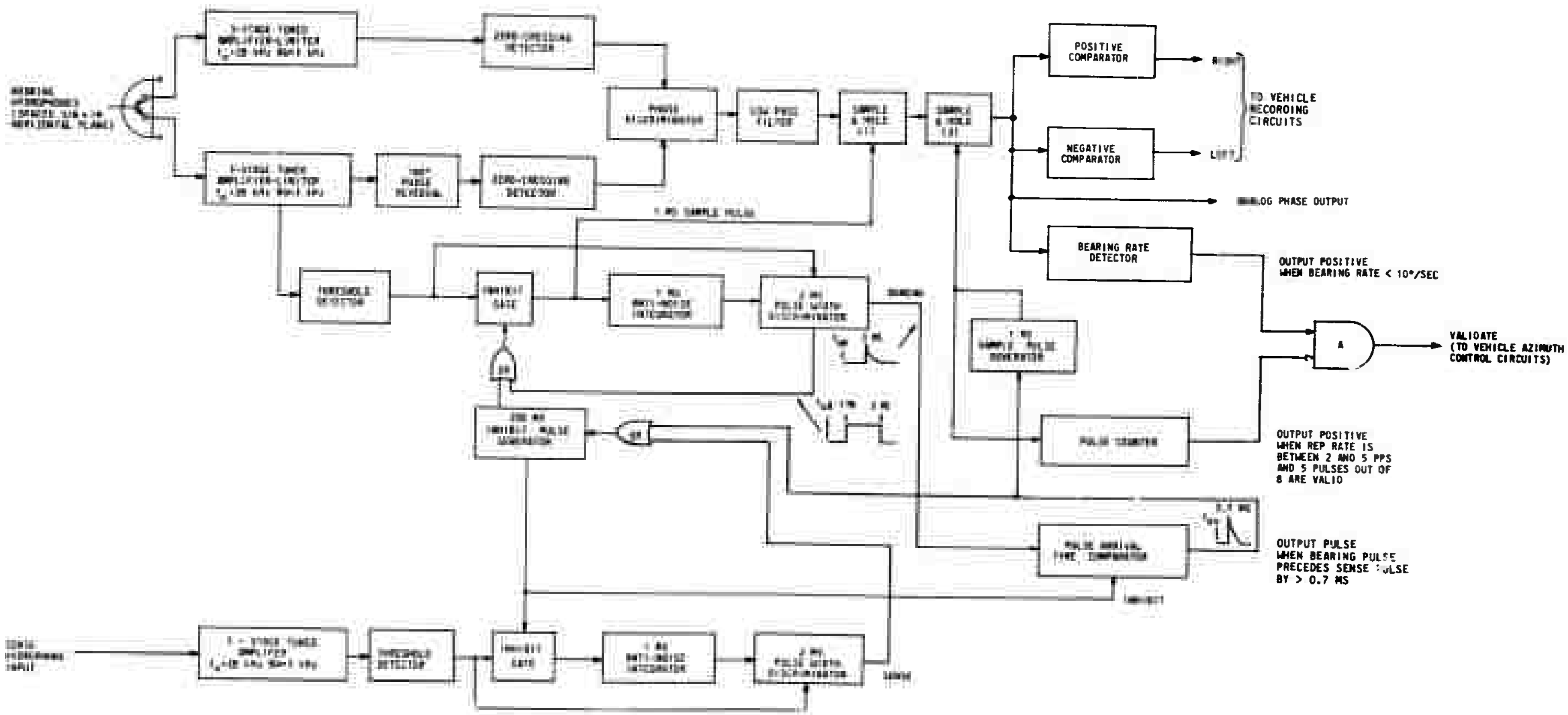


Figure 5.7. Block Diagram of Homing Receiver for UARS

are baffled on the side next to the vehicle body, to see forward only, and have -3 dB beam widths of approximately 120° in the horizontal plane and 50° in the vertical plane. The third hydrophone, referred to as the sense hydrophone, has an omnidirectional pattern and is mounted on the underside of the vehicle approximately 5 ft aft of the bearing hydrophones. Homing pulses received at this hydrophone are used to prevent homing on reflected signals. This is discussed in greater detail in the following description of the operation of the homing receiver.

Two tuned amplifiers amplify the signals received by the right and left bearing hydrophones. Their outputs are fed to zero-crossing detectors 180° out of phase and the pulse output of these detectors is used to feed a flip-flop type phase detector. The output of the phase detector is filtered and the dc component is then passed through two sample-and-hold circuits before being sent to the heading control circuits. The magnitude and polarity of the steering signal thus provided is dependent upon the directional bearing of the received signal.

Several logic decisions are necessary to avoid reverberation problems and the possibility of bearing calculations on false signals. An input to a threshold detector is taken from a relatively low gain tap from one of the bearing channel amplifiers and is rectified and filtered in the detector. When this detected signal exceeds the threshold (-100 dB input), the first sample-and-hold gate is opened, allowing a phase sample to be taken before reverberation echoes occur. At the same time the signal is tested in an integrator to verify that it remains up for a full 1 msec period, thus assuring that it isn't a noise spike. If the signal is thus verified, it continues to be tested for pulse width by the 2 msec pulse width discriminator but further phase sampling is inhibited. Thus the phase information in the first 1 msec of the pulse is stored and the pulse is tested to verify that it is at least 3 msec in width. (The width of the transmitted pulse from the homing beacon is 4 msec.)

The sense channel uses a single amplifier which is identical to one of those used in the bearing channel. The low level output feeds a threshold detector and succeeding circuits identical to the bearing channel. The two circuits are adjusted so that the times between pulse input initiation and output from the pulse width discriminators are identical (i.e., 3.0 msec within 0.1 msec).

A further test of signal validity is performed by a circuit which compares the arrival times of pulses received at the sense and bearing hydrophones. To obtain an output pulse from this circuit, the pulse in the bearing channel must arrive at least 0.7 msec before that in the sense channel. With a 5-ft separation between the sense and bearing hydrophones, an output pulse is obtained only when the direction to the homing beacon is less than 45° off the vehicle axis (at larger angles, the separation time between pulses is less than 0.7 msec). Associated with the operation of the pulse arrival time comparator is a 200 msec inhibit pulse generator. This generator is triggered either by the sense pulse or by the output from the arrival time comparator. It then inhibits further phase samples and prevents time of arrival comparisons from being performed on any reverberation following a valid pulse for a period of 200 msec.

The sense channel and time of arrival test would be unnecessary if the bearing hydrophones had omnidirectional coverage and were always able to pick up the direct pulse from the homing beacon as well as any reflected pulses. Reflected pulses, arriving after the direct pulse, could then be rejected by an inhibit action after the pulse width validation of the direct pulse. However, because of the low response in the rear pattern of these hydrophones, it is conceivable that reflected pulses might be picked up while direct pulses go undetected when the vehicle is headed away from the homing beacon. The sense hydrophone, with its omnidirectional coverage, is able to pick up the direct pulses in this situation and the time of arrival test avoids the possibility of homing on the reflected signals.

The output from the pulse arrival time comparator is used to trigger a sample pulse generator which transfers the original phase calculation to the second sample and hold circuit. The output from this circuit then provides an analog steering signal to the heading control circuits during the homing operation. The analog output is also fed to two comparator circuits which provide binary type output information to the vehicle recording circuits. The comparators are biased such that one unit gives a true or "one" output when the bearing angle exceeds 5° to the left and the other gives a true value for bearing angles greater than 5° to the right.

The remainder of the circuitry is used to further verify the validity of the signals. Unlike the other validity tests, these require the examination of phase change rate and number of homing pulses and serve primarily during the acquisition phase of the vehicle homing sequence. To obtain a validation signal (homing gate), which is then supplied to the vehicle azimuth control logic, the following two conditions are required.

(1) The phase (bearing) calculations must not vary in a random manner from pulse to pulse. More precisely, a phase rate of change greater than 10 degrees per second for five or more samples out of eight valid samples will inhibit the homing gate.

(2) At least five out of eight pulses received must be valid and the pulse repetition rate must be between 2 and 5 pps.

The random phase test is applied to the output of the second sample-and-hold circuit. On the block diagram this circuit is labeled "bearing rate detector." A positive output is obtained from the bearing rate detector only when the input bearing signal varies at a slow rate which is characteristic of a properly varying phase as seen by a vehicle having a maximum turn rate of 6 degrees per second when looking at a fixed source. This validation test, used alone, would be insufficient to verify the presence of a proper homing signal since <u>no</u> signal inputs to the system would also be interpreted as a valid signal. It is therefore used in conjunction with a pulse count verification test.

Invalidation of the homing gate is an indication to the vehicle's control system that the steering signals it is receiving are invalid. The

control system then generates zero rudder angle (straight course) for 30 seconds followed by a circle search until a valid homing signal is again received or until the run is terminated by other means.

The design of the homing system has progressed through several stages, from a simple CW system which successfully operated at 3-mile ranges in Puget Sound to the present, rather sophisticated design. The interference noise in Puget Sound is quite different from that experienced under the arctic ice. In the latter case, the reverberation or reflection of the beacon signal from the water-ice interface causes azimuthal signal distortion as well as strong Lloyd mirror effects. To a large extent, the latter problem can be ameliorated by using a pulsed system. Both CW and pulsed CW system tests in the arctic under-ice environment indicated directional ambiguity problems which could only be resolved by a rather complex logic chain.

5.9 DATA RECORDING SYSTEM

The data recording system is designed to operate with a low-speed magnetic tape recorder and obtain high-resolution, high density data recording at a relatively low data rate over long periods of time. To accomplish this, all signals are converted to binary form (sampled and converted if a continuous signal) and recorded on magnetic tape using the non-return-to-zero, change-at-one (NRZ1) recording method. A nine-track recording head is used on 1/2-inch magnetic tape, and the binary data words are recorded across the tape in a parallel-serial combination using time-multiplexing to separate the various data channels.

The magnetic tape transport design is a modification of a design originated by this Laboratory for use in SPURV (Ref. 1). Several of these units have been built and used in field operations with excellent results. These are limited-purpose units, designed for recording only, with no playback capability. However, they are very compact and have low power drain. Modifications from the SPURV design consist primarily of increasing the number of recording tracks from seven to nine and decreasing the tape speed from 3/4 to 3/8 inch/sec. The reduced tape speed permits 12 hours of data to be recorded on a single 7-inch reel of 0.5 mil base tape. Nine-track recording is used in preference to seven-track because of its increasing utilization in many of the newer computer systems (e.g., IBM/360).

The tape transport uses a capstan drive powered by a 400 Hz synchronous motor through a precision gear reducer and flat belt drive to achieve the necessary speed reduction. The 400 Hz power is obtained from a solid state inverter which has a frequency stability of ±1/4%. This arrangement gives a very precise average tape speed.

Figure 5.8 shows the channel multiplexing arrangement used for UARS data recording. Two characters are required to write a word in each channel (A through J). A character in this context refers to a vertical column across the tape. The basic character recording rate is 120 times per second which, with a tape speed of 3/8 inch per second, results in a tape recording density of 320 characters per inch. Two of the nine tracks are

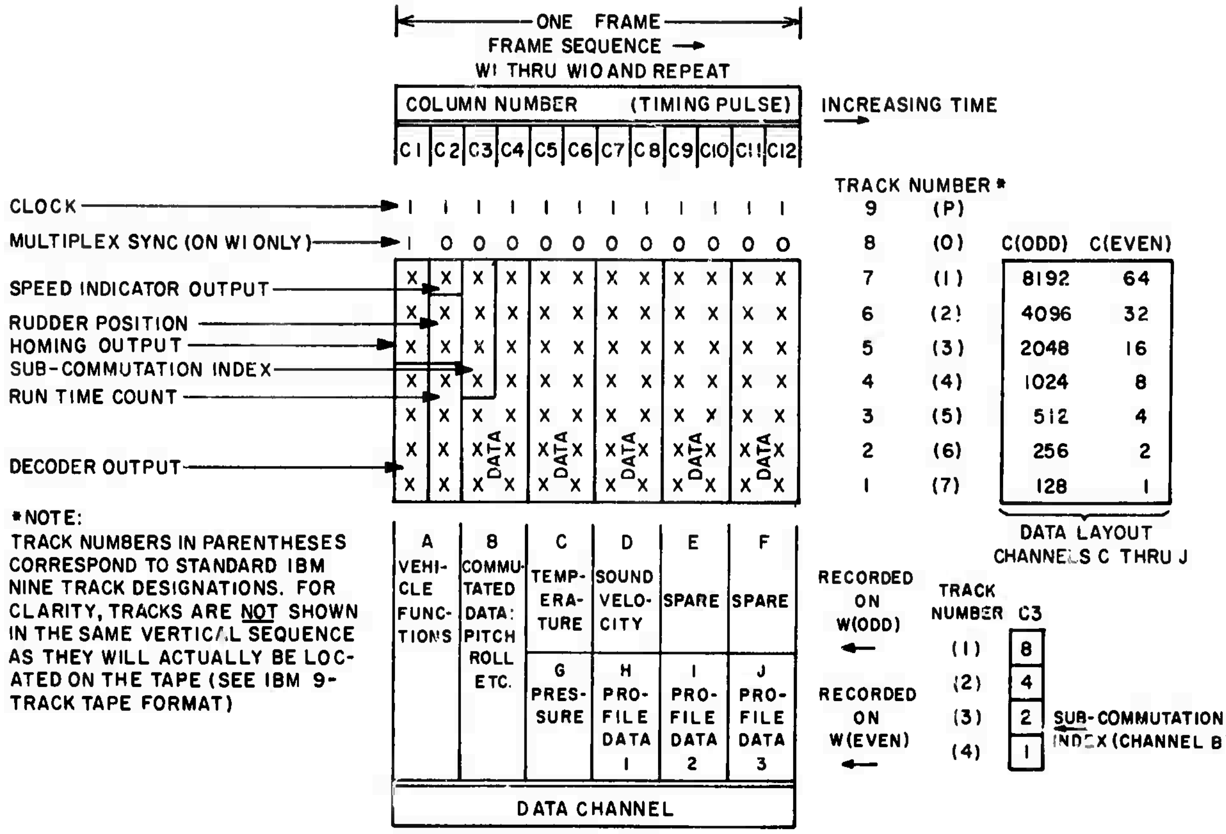


Figure 5.8. Format for UARS Data Recording

used to record the character clock and a multiplex synchronization pulse. These timing pulses are used in recovering the data from the tape. The other seven tracks contain the data portions of the words in the various channels.

One aspect of the multiplexing arrangement which may not be entirely obvious from the diagram is the timing sequence of the word counter. This counter steps sequentially and repetitively from W1 through W10 with a single step occurring at the completion of each frame as shown. Each channel is wholly, or in part, time-multiplexed in accordance with the word count as well as with the character timing pulses C1 through C12.

Channels C through J are time-multiplexed in accordance with even and odd words from the word counter to provide for inputs from eight sensors at a recording rate of five times per second. Six of these inputs have been allocated based on the present and planned instrumentation suite, and two are available for additional instrumentation. The recording rate of five times per second corresponds to a data point for each foot of travel at a vehicle speed of 3 kn. A straight binary code is used in

these channels which provides a capability for recording up to a 14-bit binary number in each word. The first character in a channel word is referred to as the "High Register", and the second character as the "Low Register" with the bit weighting for each register as shown in the box on the upper right side of the figure. The "write" commands for the characters are referred to as High Register Write (HRW) and Low Register Write (LRW).

Channel B contains the output from a 10-bit analog-to-digital converter. In general, all signals to be recorded in this channel are of a slowly varying nature, such as battery and secondary supply voltages, pitch, roll, etc. The signals are commutated at the input to the A/D converter by a solid state multiplexer which is stepped with the word count. In addition, a subcommutation is performed on signals which need to be recorded only infrequently, such as battery and supply voltages. At the present time only the W1 position is subcommutated. A four-bit index is included along with the subcommutated data to identify the particular signal being recorded. The location of the ten data bits in this channel is indicated in the figure and the weighting of the bits is the same as shown for channels C through J in the corresponding bit locations. The location and weighting of the index bit positions are also shown in the figure. A total of 16 subcommutated signals can be recorded in the W1 position at a recording rate of one every 16 seconds.

Channel A is a "catchall" channel. One of its functions is to record the occurrence of off/on type outputs such as rudder actuations and the vehicle speed indicator output. The sampling rate (recording rate) is ten times per second, and the presence or absence of a bit in the positions shown indicates the on/off state of the function indicated. Four bit positions in this channel are time-multiplexed in accordance with the word count in order to record a 16-bit binary number containing the count in seconds of the elapsed time since the occurrence of the external synchronization pulse at the start of the run. The multiplexing arrangement and the weighting of the bit positions is shown in Figure 5.9. Also included in this channel is the four-bit binary coded acoustic command last

W1 C2	W2 C2	W3 C2	W4 C2	TRACK NUMBER
2^3	2^7	2^{11}	2^{15}	(4)
2^2	2^6	2^{10}	2^{14}	(5)
2^1	2^5	2^9	2^{13}	(6)
2^0	2^4	2^8	2^{12}	(7)

Figure 5.9. Multiplexing Arrangement for Recording Run Time Count

received by the vehicle and the outputs from the homing receiver. Vehicle velocity with respect to the water is recorded by inputs from a propeller-type speed sensor. The propeller drives a small magnet past a reed relay whose contact closures are counted down for recording in the single bit position shown.

A block diagram of the complete data system is shown in Figure 5.10. A detailed description of the frequency-to-binary conversion used for recording pressure, temperature, and sound velocity, and the A-D conversion used for recording pitch, roll, elevator angle, etc. is given in Ref. 5. Reference 2 contains a description of a digital depth reference and depth error detector similar to the one used in this vehicle. Design changes in this latter unit have been made to allow greater latitude in the selection of preset running depth, but the basic technique remains the same.

5.10 PROFILER

The primary instrumentation for the UARS is the under-ice profiler. This unit consists of a wide beam transmitter and a multiple narrow beam receiver array. A multiple beam acoustic transducer-lens system, developed by this Laboratory, is used for the receiver array. The combined directivity pattern for this array at the operating frequency of 500 kHz and for three transducer beams is shown in Figure 5.11. Each beam is associated with a particular transducer of the array. The fan-shaped array is mounted in the vehicle in an upward-looking direction with the plane of the beams perpendicular to the vehicle center line.

The profiler transmitter is similar to the one used in the obstacle avoidance sonar, having a pulse width of 150 μsec (vice 200 μsec), a peak power output of approximately 100 W, and a pulse repetition rate of five pulses per second, but with an operating frequency of 500 kHz.

Separate, but identical, receivers are used to amplify and detect the returns from the under-ice surface in three beams. The receivers employ a combination of time-varied gain (TVG) and pulse width discrimination to reject false trips from volume reverberation or biological sources.

The detected under-ice surface returns from the three profile receivers are sent to the profile recording circuits which determine the time of arrival of the returns with respect to the transmitted pulse, and encode it as a 10-bit binary number for recording on the magnetic tape. A block diagram of the profile recording circuits is shown in Figure 5.12.

Each beam has a separate 10-bit binary counter which is reset to zero and starts counting at a 10 kHz clock frequency at the start of the transmit pulse. Each counter is stopped at the time of arrival of a return in that particular beam or, in the event of no return, when the counter recycles to zero. At the 10 kHz clock frequency, each bit corresponds approximately to 1/4 ft in range (0.1 msec); the maximum

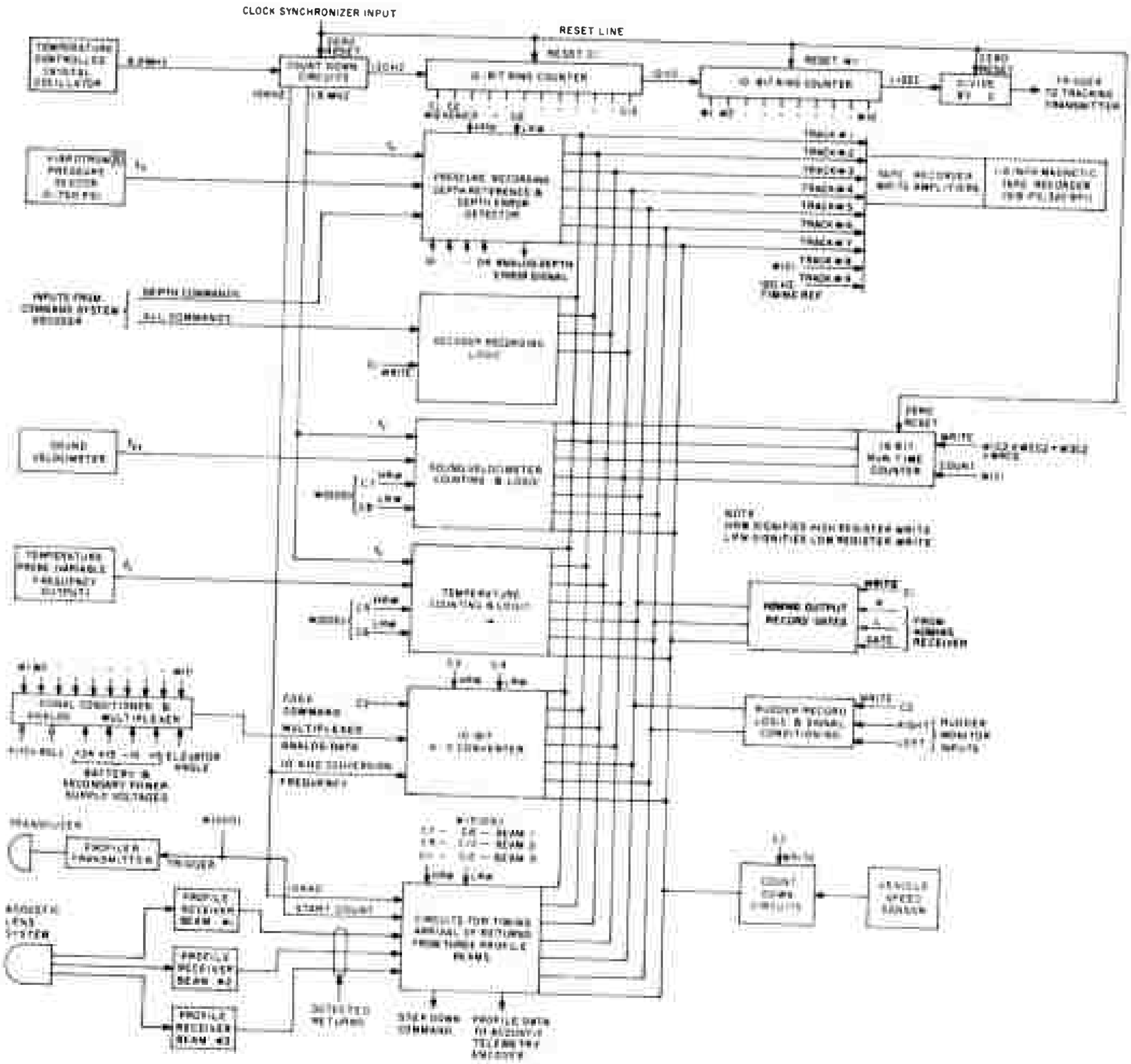


Figure 5.10. Block Diagram of UARS Data System

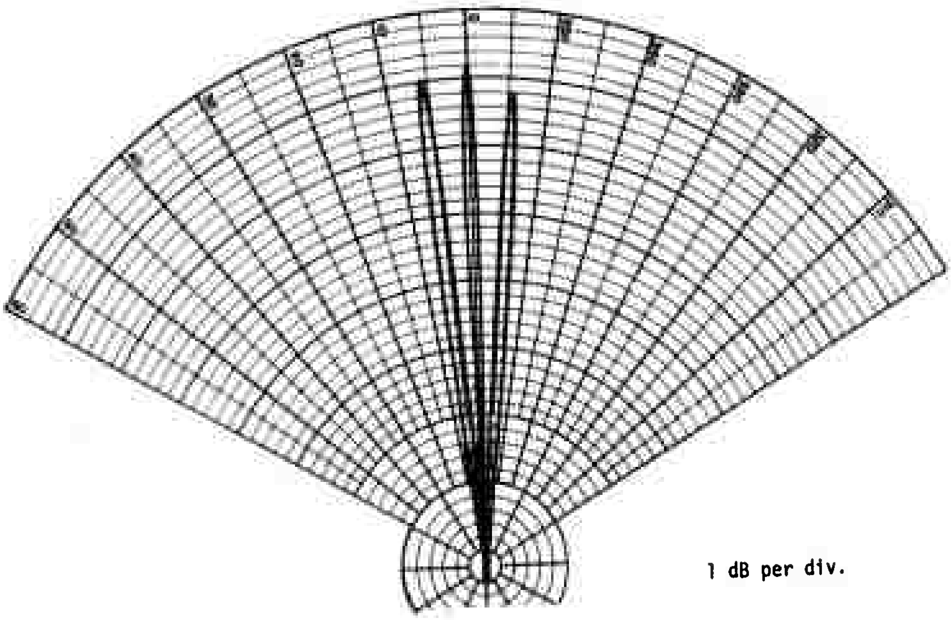


Figure 5.11. Directivity Pattern of Three-Beam Transducer Lens System

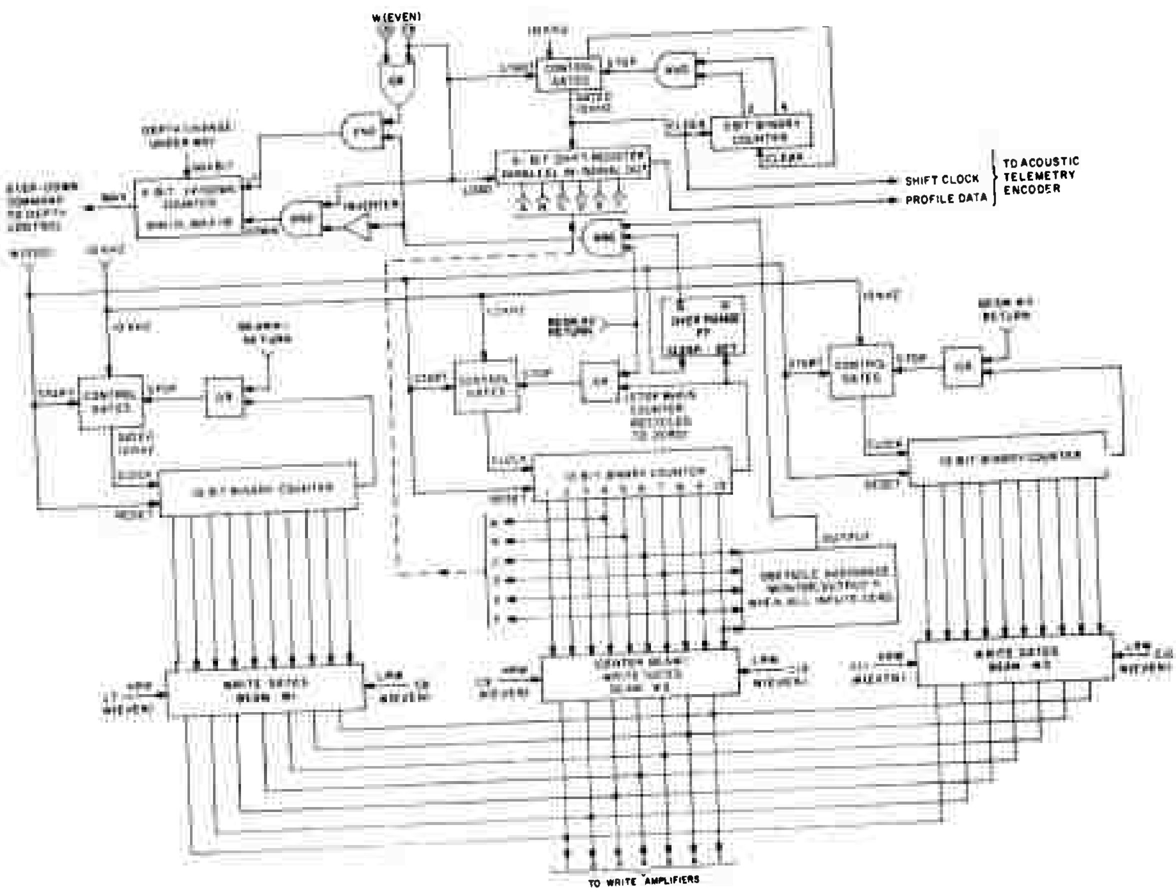


Figure 5.12. Block Diagram of Profiler Recording Circuits

range which can be recorded is 1023 bits or approximately 255 ft. The write pulses (HRW and LRW) for recording the counters occur after the maximum range time but prior to the next transmit pulse.

The obstacle avoidance monitor on the counter for the center beam provides a positive output whenever the number in the counter is less than 32, which corresponds to a range of less than 8 ft. If such a return occurs, an "up" count of 2 is placed in a 4-bit up/down counter by the record pulses C_9 and C_{10}. If no return occurs or its range is greater than 8 ft, a single "down" count is entered. Thus, a running count is made of returns occurring at a range of less than 8 ft. If these returns occur more than 30% of the time, the counter will reach a maximum count of 10 and put out a "step down" command to the depth control circuits. It is expected that this would occur only in the event of failure of the forward looking obstacle avoidance sonar or if the underside surface of the ice cover has a very shallow slope (increasing in depth) and a very smooth surface so that returns (at the low grazing angle) into the sonar are below the threshold level. An inhibit line prevents further stepdown commands from the up/down counter until the previously commanded depth change is completed.

Data from the center beam is also sent to the acoustic telemetry encoder for transmission (via the tracking pulse) to the tracking site. The data consists of a 6-bit binary word in which the least significant bit corresponds to approximately a 2-ft range. This data is used for vehicle navigation purposes and does not require the resolution of the internally recorded data.

5.11 TRACKING TRANSMITTER AND COMMAND RECEIVER

The tracking transmitter and command receiver are discussed together because they function as a two-way acoustic telemetry link between the tracking station and the vehicle. The tracking transmitter, of course, has the separate function of providing an acoustic pulse suitable for tracking the vehicle's position. Both the tracking and command pulses are digitally coded using 100% phase shift keyed modulation at a carrier frequency of 50 kHz with a nominal source strength of 97 dB. Allowing five cycles of the carrier per bit, a 13-bit word is transmitted with a pulse width of 1.3 msec.

Acoustic tests of this system have been conducted in Puget Sound using the transmitter-receiver depths (approximately 50 and 300 ft) planned for the initial arctic applications. These depths, during the winter test season, were adequate to prevent overlap of the direct and surface reflected pulses. The system demonstrated reliable data telemetry out to the range limits implicit in the developmental model, in excess of 2000 yd. Tests of the same system were conducted under ice in the Arctic in April 1971 and similar results were obtained. The arctic tests indicated that higher medium absorption losses, because of lower water temperatures, did not adversely influence the system transient (high frequency) response required to accomplish the phase shift detection

necessary in the decoding. The arctic developmental instrumentation also included successful test of an additional code validation feature which requires that the decoded phase of any bit be within ±60° of the proper phase associated with its binary state. This feature, in conjunction with parity checks, gives extremely low probability of an erroneous message being accepted as valid. It does mean, however, that some valid messages will be rejected because of bits failing to meet the phase requirement due to noise, even though they were properly decoded.

A synchronous clock mode of control for the tracking transmitter is used. In this mode, two highly stable clocks, one in the submersible and one at the control processor, are synchronized before vehicle launch. The submersible clock commands transmission at precise times known to both clocks. In order to maintain a tracking accuracy of ±1 ft over a run period of 10 hours, a time base stability of 1×10^{-8} is required. The commercial temperature-controlled crystal oscillators obtained for this use have a frequency stability of 5×10^{-10} over a 24-hr period when held at constant temperature. Their variation with temperature is less than 2×10^{-9} over the temperature range from -55°C to +60°C. Since a stable crystal oscillator and associated count-down circuits are also required in the data recording system, the same oscillator is used for both purposes.

Tracking pulses are transmitted from the vehicle at 2-sec intervals, which provides for a 10,000-ft unambiguous tracking range. As previously mentioned, the tracking pulse itself contains a 6-bit data word from the center beam of the profiler. Because of the large amount of other information to be acoustically telemetered to the tracking station, and because of the restriction on pulse length (to avoid multiple path interference), additional coded pulses are sometimes transmitted on the 1-sec mark between tracking pulses. These pulses are transmitted either in response to a command received at the vehicle from the tracking station or when alert codes have been generated internal to the vehicle. In the first instance, only a single pulse is sent for each command received. However, pulses indicating an alert situation continue to be sent between tracking pulses until the alert is acknowledged by command from the tracking station.

Identity codes are used to distinguish the various coded pulses transmitted by the vehicle (i.e., tracking, alert, command response) and to identify commands transmitted to the vehicle. In addition, codes have been allocated for signals to and from other objects which may be tracked or communicated with during a vehicle operation. Figure 5.13 shows the pulse coding used for the various tracking and communication signals.

Table 5.3 lists the vehicle alert situations which are to be transmitted to the tracking site. Since these are independent events, each alert is indicated by the presence of a "1" in a particular bit position in the data portions of the word with a Status 1 identity.

Status 2 codes are sent alternately with the Status 1 codes and contain information regarding the homing status of the vehicle. This information is particularly useful during the homing acquisition and

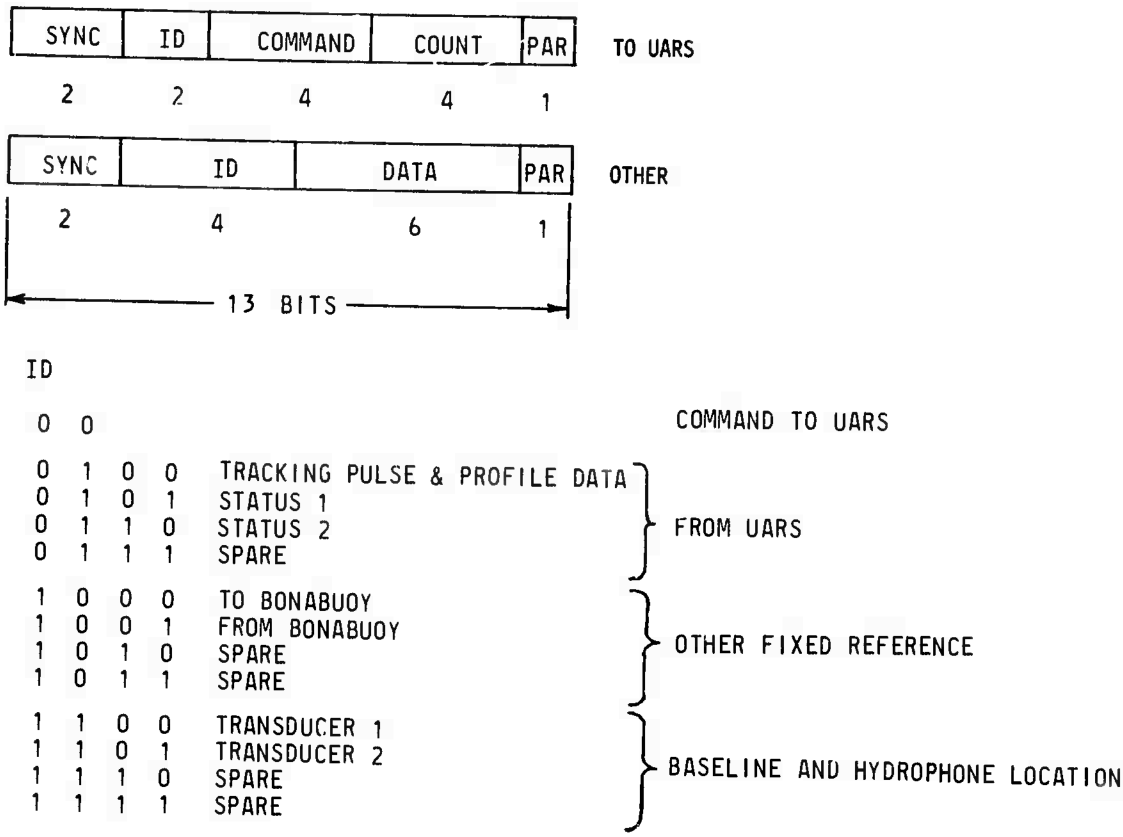


Figure 5.13. Acoustic Communication Binary Code

Table 5.3. Submersible Alert Signals

1. Low Battery Voltage - Main
2. Low Battery Voltage - Reserve
3. Loss of Command - 180° Turn
4. Propulsion Motor Shutoff
5. Obstacle Avoidance from Forward-Looking Sonar
6. Obstacle Avoidance from Profiler

control phase of a vehicle run. Table 5.4 lists the status information transmitted to the tracking site by the Status 2 codes. Items 5 and 6 in the table are not related to homing status but are to inform the tracking operator when the vehicle has received and acted upon the indicated commands. The importance of this is discussed later.

Table 5.4. Vehicle Status Information Transmitted by Status 2 Codes

1. Homing search started
2. Homing gate present
3. Homing control active
4. Homing circle active
5. Large step command inhibited
6. Obstacle avoidance sonar inhibited

A command response from the vehicle contains a 2-bit code in the data portion of the word indicating the vehicle's acknowledgement of the command as follows:

00	command, accepted, and acted upon
01	parity OK, non-redundant, command stored
10	parity error, command rejected
11	busy, still working on last command

To reduce the false alarm probability in the command link, each command received by the vehicle is checked for parity and also compared bit by bit with the last received command. For a command to be accepted and acted upon, it must be identical to the last command (including the count portion) and have the correct parity count (i.e., even number of "1's" in the word). If the parity is correct but the command is not the same as the last, it is not acted upon but stored for later comparison with the following command. Also included in the data portion of the command response is a 2-bit code indicating the operating depth setting (i.e., D1, D2, D3, or D4) of the vehicle at the time the word is transmitted and a 2-bit count of the false trips registered by the command receiver since the last command response.

A list of commands to be sent to the vehicle is given in Table 5.5. Associated with each step up, down, right, or left command is a 4-bit "count" code indicating the desired number of steps. A 4-bit binary number does not allow sufficient incremental 3° steps for a 180° turn which is a fairly command command. A weighting scheme overcomes this problem. Starting from the most significant bit, the weighting for the 4-bit positions are 40, 20, 10 and 5 steps with a 0 in all 4-bit positions indicating a single 3° step. This permits, with a single command, large heading changes in multiples of 15° up to a maximum of 180°, while small heading corrections can still be made in 3° increments. The magnitude of a single up or down step is adjustable from approximately 0.1 to 0.64 ft/step. The number of steps per command is coded the same as for heading changes.

Table 5.5. List of Commands to the Vehicle

COMMAND CODE	COMMAND	
0000	Step Right	On these commands, the number of steps to be taken will be coded in the "count" part of the word.
0001	Step Left	
0010	Step Up	
0011	Step Down	
0100	D1	Four preset depth commands. These commands will also start propulsion motor.
0101	D2	
0110	D3	
0111	D4	
1000	Start Homing	
1001	Stop Homing	
1010	Alert Acknowledged	
1011	Send Status Data	
1100	Inhibit Obstacle Avoidance Sonar	
1101	Large Step Acknowledged	
1110	Spare	
1111	Stop Propulsion Motor	

Sending step commands to the vehicle can present a problem if communications with the vehicle (i.e., commands to the vehicle or command responses and tracking pulses from the vehicle) are obtained only intermittently as may occur at long ranges. Under these conditions, the usual practice is to send a command repetitiously and as rapidly as the system will allow until the proper command response is obtained from the vehicle. If step commands are sent in this manner and if conditions are such that the vehicle receives commands more often than the tracking station receives the command responses, an erroneous number of step commands will be acted upon by the vehicle. Unfortunately, the command most likely to be sent under these conditions is a 180° step turn command to bring the vehicle back into reliable communication range. Obviously, it is important that the vehicle only respond to one such command even though it may receive many. To correct for this problem an inhibit circuit has been incorporated into the vehicle depth and azimuth stepping system such that whenever a step command of greater than a single step is received, further large steps are inhibited until an acknowledged large step command is received. Receipt of a large step command also activates the transmission of Status 1 and Status 2 pulses informing the tracking operator of the inhibit condition by the presence of a "1" in an assigned bit position of the Status 2 code (see Table 5.4). The inhibit circuitry is not activated by small step commands since it is not likely that they would be sent under the conditions described above and it would unnecessarily increase the number of commands required to send small course corrections during the major portion of a run when the vehicle is within good communications range.

A command to inhibit the obstacle avoidance sonar from changing vehicle depth has been provided. This is used only in the final phase of vehicle recovery and prevents the vehicle from avoiding the recovery net. Should this inhibit condition occur because of a false command during a normal run, the vehicle would be in a vulnerable position. This condition is therefore treated as an alert condition and notification that the inhibit is active is relayed to the tracking operator by a "1" in a bit position of the Status 2 code as previously mentioned.

Block diagrams of the command receiver/decoder and the tracking transmitter/encoder are shown in Figures 5.14 and 5.15, respectively. The major features and operating characteristics of these systems have already been discussed in the foregoing paragraphs. The remainder of this section discusses some details which may not be obvious from the block diagrams.

The command receiver comprises three major components: a bandpass amplifier, a signal processor, and a decoder. The significant characteristics of the bandpass amplifier are listed on the diagram. The amplifier also contains an AGC (automatic gain control) circuit which lowers the gain from that shown by an amount dependent on the background noise level. The AGC is capable of reducing the gain by as much as 40 dB in an extremely noisy environment.

The amplified PSK (phase-shift-keyed) signal is demodulated in the signal processor and the resulting digital word is loaded into a shift register. The signal processor also accomplishes a preliminary validation of the incoming command by checking the parity and ID of the digital word and placing the following requirements on the incoming signal pulse:

(1) that the signal after crossing the set threshold detection level (which starts the signal processing) remain above that level during the entire time the digital word is being clocked into the input register

(2) that a 180° phase shift occur in the signal within approximately 140 μsec after crossing the threshold level

(3) that the phase of the signal be within ±60° of its two expected states (i.e., 0° or 180° with respect to its initial phase after crossing the threshold level) at each bit time.

Demodulation of the PSK signal requires that a reference phase be established. This is accomplished by dividing by 30 a 1.5 mHz reference signal from the vehicle data system to obtain the 50 kHz reference. Resetting of the "divide by 30" circuit at a zero crossing of the incoming signal locks the phase of the 50 kHz reference to within 12° of the incoming signal. (Each cycle of the 1.5 mHz corresponds to 12° at 50 kHz.)

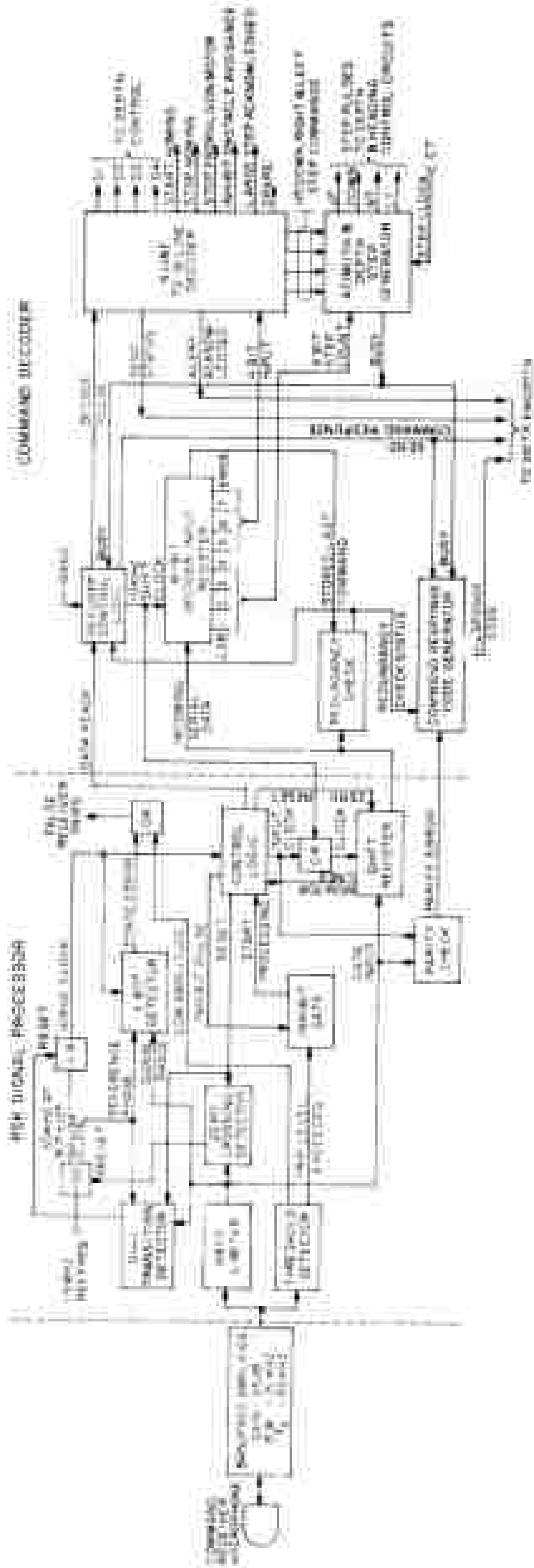


Figure 5.14. Block Diagram of UARS Command Receiver/Decoder

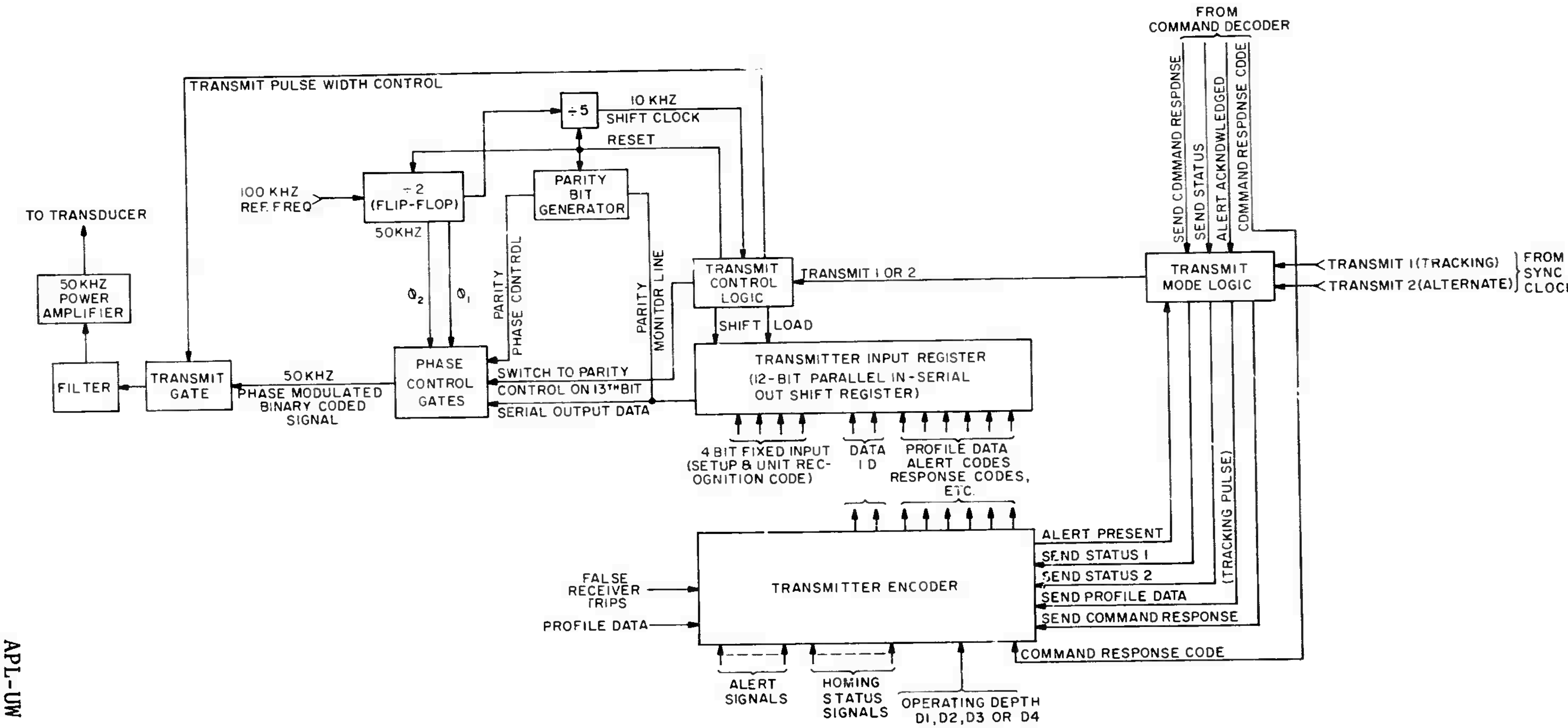


Figure 5.15. Block Diagram of UARS Tracking Transmitter/Encoder

The first two bits received (the setup code) are always 01. Phase locking is accomplished during the first bit and the 0-to-1 transition is used to establish the bit timing. Phase locking occurs whenever the signal exceeds the threshold level and is completed in two cycles of the 50 kHz signal. A 100 μsec timing circuit is activated at the end of the phase locking sequence and the signal is examined during the 100 μsec interval for the 180° phase shift corresponding to the 0 to 1 transition. If the proper phase shift occurs within the allowed time interval, a circuit which divides the 50 kHz reference by five is enabled so as to provide a clock pulse during the third cycle of each bit for demodulating the incoming signal. If the expected phase shift does not occur during the 100 μsec period and the signal level is still above threshold, the phase locking sequence and 180° phase shift search are repeated. Should the signal level fall below the threshold at any time during the above sequence or while the word is being clocked into the register, the signal processing is stopped and the word is rejected. The logic here is that while noise alone may cause many false starts, it will be rejected by the threshold or phase shift requirements. However, to increase the likelihood of picking a true signal pulse out of a noisy environment, restarts are made as soon as it is determined that the signal being processed is invalid.

Demodulation of the PSK signal is accomplished by sampling the hard limited signal (clocking it into the shift register) at a 90° reference time of the third cycle (out of five) of each data bit. At this time the limiter will be in the middle of its negative output swing if the data bit is 0 and will be in the middle of its positive swing if the data bit is a 1. When the data is clocked a reject signal is set if the limiter output is not within ±60° of its 0 or 180° expected value.

The control logic in the signal processor resets the shift register to 0 at the start of each signal process. It then monitors the last three bit positions in the 12-bit register as the digital word is shifted in. The 1 bit of the setup code is the first bit clocked into the register. Thus, when this 1 bit reaches the final bit position, the signal processing is stopped, and, providing the ID is 00 (indicating the presence of a command word to the vehicle), a data ready pulse is sent to the decoder section. At the same time, a 200 msec inhibit gate is activated which prevents signal processing on the reverberation following a pulse.

If a parity error is present in the incoming command, or if the decoder is busy on a long step count from the last command, the only action taken by the decoder control logic when the data-ready pulse is obtained is to generate a command response indicating the parity error or busy condition. When the above conditions are not present, the receipt of the data-ready pulse will cause the 8 bits of the command word containing the coded command instruction and associated step count to be shifted into the decoder input register. As the digital word is shifted into the register, it is compared bit by bit with the preceding word which has been stored in the same register. If they are identical, a decode pulse is sent to the decoder (4 to 16 lines) which decodes the command from the

4-bit instruction portion of the word and sends it on to the proper vehicle system. When the instruction is a step command, the 4-bit step count is loaded into the azimuth and depth step generator which generates the indicated number of step pulses and transmits them to the appropriate heading or depth control circuit. If the incoming command is not identical to the stored command, it is said to be "non-redundant" and a decode pulse is not generated. However, the register retains this command for comparison with the following command and a command response is generated indicating the "non-redundant" status of the last received command.

Note from the tracking transmitter/encoder block diagram that the transmit mode logic circuits select the type of data to be transmitted depending upon whether the transmission is at transmit 1 (tracking pulse) or transmit 2 (1 sec interval between tracking pulses). Transmit 1 data is always transmitted but transmit 2 data is sent only in response to commands or to convey "alert condition" data. After selection of data, the logic circuits send a pulse to the transmit control logic which parallel loads the digital data into the transmitter input register and starts the generation of the phase modulated signal. The phase modulation is accomplished digitally. A 100 kHz reference signal from the data system is fed into a flip-flop to generate two symmetrical waveforms at 50 kHz which are 180° different in phase. The output of the shift register controls which of the two phases is output from the transmitter, +90° for a 1 and -90° for a 0. Five cycles of the 50 kHz waveform are transmitted for each bit of data. The control logic gates the phase generator output through a filter to the transmitter power amplifier while it shifts the data bits one at a time into the generator. The filter removes all but the fundamental frequency of the square wave signal fed into it and produces a sinusoidal phase shift keyed signal for transmission. The transmit control logic counts the number of shifts and switches phase control to the parity bit generator on the 13th bit. The parity bit generator monitors the data as it is output from shift register and sets the phase of the 13th bit so as to produce an even number of 1's in the data word.

5.12 EMERGENCY RECOVERY PINGER

The emergency recovery pinger is mounted in a special housing within the flooded tailcone. The commercial unit used in this application is self-contained in a cylindrical shape 4 in. long and 1.3 in. in diameter. It is self-activated by immersion in salt water and puts out a few millisecond wide pulse, once or twice a second at a frequency of 37 kHz. Its in-water output signal level (peak value during pulse) is approximately 68 dB (ref. 1 μbar at 1 yd) and it has an operating life of 21 days on its internal battery. To increase reception range, a corrosion link release mechanism has been designed to allow the unit to drop from its housing on a tether line (normally coiled in the back of the housing) to a depth of several hundred feet below the vehicle after an immersion period of approximately 14 hours. This link is replaced before each run. The primary battery power source is replaced after each run.

5.13 FLASHING LIGHT

Initiation of the homing sequence activates a strobe light which flashes at a rate of two flashes per second. This lamp is installed inside a transparent port in the nose section. The light is visible from the surface in the clear water of the Arctic, thus the trajectory of the vehicle can be observed during the final homing phases, and appropriate compensations can be made if near misses of the net are observed.

6. UARS SYSTEM TEST PROGRAM

6.1 GENERAL

The UARS system test program began a few months after the start of the design phase when breadboard versions of the acoustic homing system and command/communication link underwent preliminary testing in Puget Sound. By March 1971, all of the acoustic systems had been breadboarded and packaged in such a manner that they could be readily tested in the field. By that time, work had progressed to the point where tests in the arctic under-ice medium were necessary to resolve questions relating to the acoustic properties of the medium, the signal return character of the ice undersurface, and the effectiveness of the planned signal processing and validation logic techniques. In early April, field tests of breadboard models of the obstacle avoidance sonar, profiler, homing system, and command/communication system were made in the under-ice environment in Colby Bay at Fletcher's Ice Island (T-3). At that time, the ice island was at 85½° North and 88½° West. These tests were reported in Ref. 6.

One result of these acoustic system tests was the verification of our design approach (insofar as possible from static, under-ice testing) to the tracking/communication system, the obstacle avoidance system and the profiler transmitter/receiver system. However, the results of the homing system tests were of great concern. The standing wave pattern which resulted from continuous transmission from the homing beacon gave rise to signal reinforcement and almost complete cancellation (at least below ambient noise) in the classic Lloyd mirror manner as the homing transducer was moved vertically. Moreover, when the transducer was rotated, the sensed direction of the acoustic signal fluctuated widely, as the horizontal component of the under-ice surface scattered signal gave rise to spatially coherent, stationary wave fronts of odd curvature. The obvious solution to this problem was to revert to pulsed operation and to devise a proper logic to reject the reflected signals. (The homing system design is described in Section 5.)

Further under-ice system tests were conducted in conjunction with the ARPA-sponsored Marginal Ice Zone (MIZ), Pacific research program during August 1971 in the Chukchi Sea, northwest of Barrow. During these tests, the same instrumentation that had been used during the April 1971

tests at T-3 was employed. These results are reported in Ref. 7. In general, the shallow sea limited the geometrical approach to signal overlap (coded pulse transmission) and imposed a restriction on pulse length, hence information content, of a single transmission. Another observed effect was the occasional existence of a fast sound channel. This was noted in pulse reception which had a low amplitude precursor pulse of several tenths of a millisecond, followed by a saturation amplitude, full-length pulse. Frequently, the precursor pulse appeared to be able to supply the code recognition characteristic (01 bits), causing the following main pulse (which started again with 01 recognition bits) to be read as data by the decoder. There are several approaches to resolving this problem, all of which result in a lower data rate. This problem is directly related to the sound velocity profile and appears to be most serious during the summer season in the marginal seas. In the central arctic regions, it does not constitute a serious operational problem since these channels can be vertically located and on-axis transmission avoided by locating the acoustic elements at different depths.

The revisions to the acoustic homing system and the new logic devised as a consequence of the central arctic test a few months earlier are considered adequate to cope with the MIZ acoustic environment. The data (analog recording of hydrophone pair signals as well as steering outputs) from both the central arctic tests in the spring and the MIZ summer tests provided the basis for evaluating the homing system logic presently implemented in UARS.

Another important development from a series of arctic tests (April 1971, T-3; August 1971, MIZ; September 1971, Greenland Sea; March-April 1972, T-3) was the technique of thermal cutting or coring of ice. The UARS system requires a nominal 4 x 12 ft rectangular hydrohole in the ice for normal vehicle launch and recovery. Holes must also be made for inserting the acoustic tracking, baseline and command transducers through the ice. Since these require only relatively small holes (9-in. diameter) they can be made in ice up to about 17 feet thick by mechanical boring. At greater depths, the weight of the auger and increased friction rapidly reduce the probability of making the hole (or salvaging the auger string). At 25 feet the probability is almost zero. The thermal cutting system developed in this program allows rather effortless cutting of these holes and provides a ready means for recovering frozen-in instrumentation by coring out the part.

This system and its development have been described in some detail in Refs. 6 and 7. Basically, it provides thermal energy in the form of warm water (about body temperature) for melting ice. The warm water is delivered by hose to a cutting manifold which is shaped in the plan outline of the groove to be cut in the ice (cookie cutter fashion). Downward-facing orifices allow the water to scour the ice by convective heat transfer. A groove of the desired width is obtained by proper selection of orifice size, spacing, fluid velocity and temperature. Another manifold, mounted directly above the delivery or cutting manifold, sucks the melt water out of the groove so that refreezing does not occur. As the

cut progresses to the bottom side of the ice, a free-standing column, or core, is left. Sea water seeps in near breakthrough; at breakthrough, the cutting head is withdrawn and the ice core disposed of by pushing it down through the hole with either a pole or a tethered weight. The system described in Ref. 6 was strictly breadboard; that described in Ref. 7 made 28-in. diameter holes in Greenland Sea ice. Ice thickness varied from 14 to 18 feet with penetration rates of 5 feet per hour. With the latest version, 4-ft square hydroholes were cut (in four, 2-ft square columns to facilitate disposal) at the rate of 2.4 ft per hour. The launch/recovery hydrohole for the UARS operation was made in ice up to 28 feet thick by cutting three adjacent 4-ft square holes. Each hole was made in one working day by a two-man crew. Figure 6.1 describes the hydrohole geometry.

As the fabrication of the UARS system progressed, the various subsystem designs were subjected to thorough systematic environmental tests. Principally, this meant thermal cycling and operations tests at expected

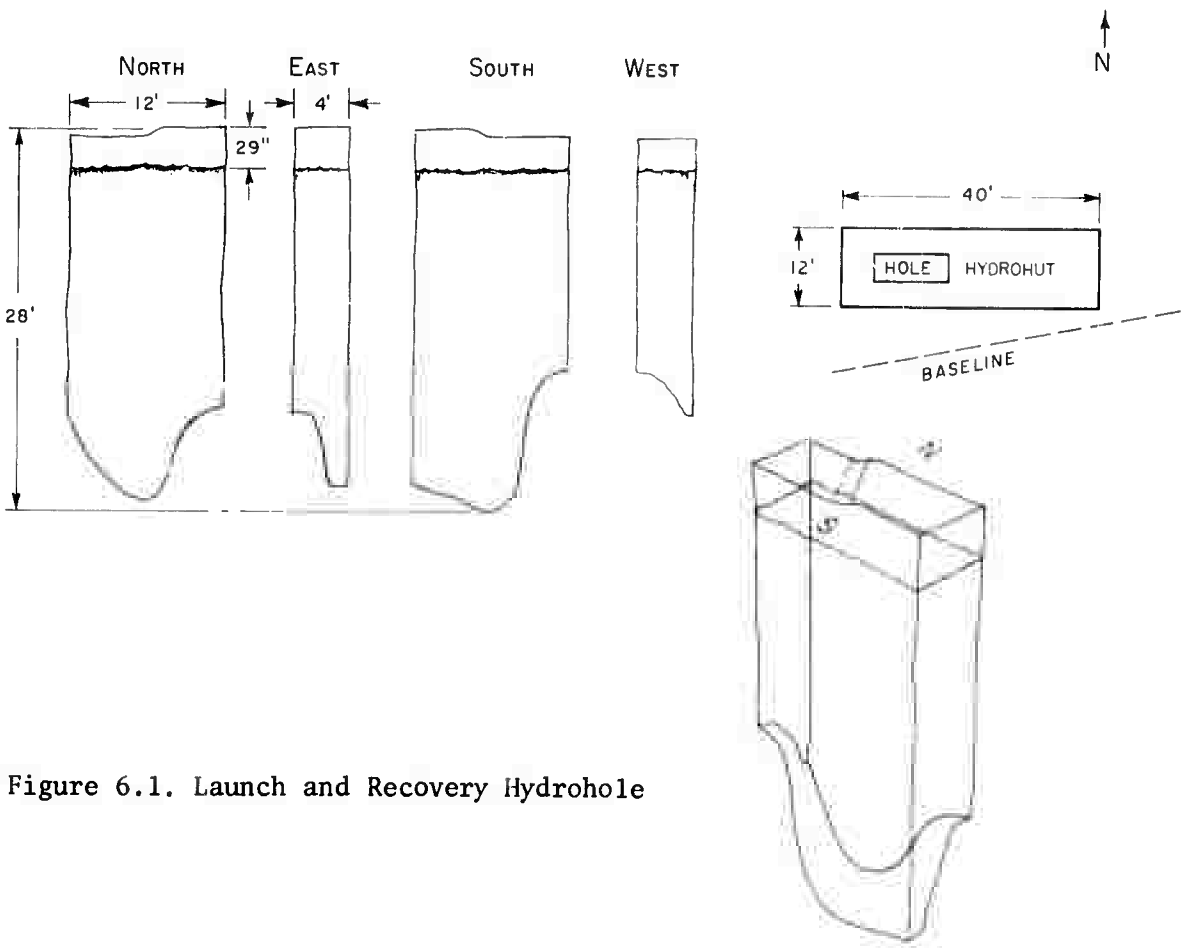


Figure 6.1. Launch and Recovery Hydrohole

conditions. For example, the internal components of the UARS encounter extreme low temperature environments only under storage conditions, while operating conditions range from room temperature down to a few degrees below the freezing point. Tracking buoys, however, see somewhat of a reverse temperature scenario. During deployment they may be exposed to temperatures around -40°C and their electronic systems are activated while at that temperature. These assemblies subsequently reach a temperature near that of sea water. The laboratory test program resulted in the detection of several marginal electronic circuits. Mechanical and sealing problems caused by thermal cycling were less numerous. The most serious problem arose in the acoustic lens system for the profiler. The original design utilized acrylic plastic outer lens elements and silicone rubber inner elements. After exposure to several thermal cycles from room temperature to -60° F while in its up-looking, operational position, the silicone rubber inner lens separated from the acrylic lens, entrapping air between the materials on the next thermal cycle. This, of course, decoupled the elements acoustically. After some fast soul searching, we concluded that the problem was so fundamental that only a pressurized fluid inner element would be reliable. Such a lens was designed and built -- its testing was completed just a few days before the system was shipped to the Arctic.

The hull systems and complete hull assembly were tested to design pressures and given what cycling test time would allow. The only problem that developed was a leaking dry-seal pipe thread that was used in the Vibrotron* pressure transducer calibration circuit. The part was replaced. Scratches on the beveled seal surfaces of some hull sections (caused by careless disconnection of anodizing electrodes during plating) were detected prior to pressure testing and polished out. Several of the strobe light components failed at different times during the laboratory and local in-water tests. This problem was never satisfactorily resolved. During the arctic tests the light functioned without fail on every run. However, erratic flash rates during bench tests led to component replacement on two occasions.

The laboratory bench tests of the complete UARS vehicle were begun in February and several interaction problems arose. Most of these were caused by grounding, power supply interaction, and wiring proximity problems -- the remainder were wiring errors. All were satisfactorily corrected. The only exception to this again involved the flashing light system. When it operates, the discharge of the storage capacitor creates transients which couple into the profiler system's data recording, creating enough noise to make that data useless. However, this light is on only during the homing phase when the emphasis is on UARS recovery.

6.2 LAKE WASHINGTON FIELD TESTS, FEBRUARY-MARCH 1972

Preliminary field tests of a UARS and an abbreviated version of the vehicle tracking system were made in Lake Washington during March 1972. Our acoustic barge was used as the platform for launch and recovery of the vehicle and housed the tracking computer and associated equipment.

---

*®

Only two tracking buoys were used in this operation vice four buoys in the arctic under-ice operations. Since these tests were being performed in open water, the buoys and the barge were anchored to hold them in a relatively fixed relationship.

A total of 20 vehicle runs, varying in length from 5 to 30 minutes, were made during these tests. The principal objectives of the runs were:

(1) test the equipment and techniques that would later be used in the Arctic for launch and recovery of the vehicle through a hole in the ice

(2) check the dynamic characteristics of the vehicle and make adjustments in control system gains where required

(3) test the principal features of the tracking and command system; i.e., tracking buoy performance, RF data telemetry from buoys to computer, computer interface electronics, computer tracking in real time, etc.

(4) check the in-water performance of the various component systems of the vehicle, making adjustments where required (a complete test of the obstacle avoidance and the emergency recovery systems was precluded by the open water)

(5) locate any interaction problems between systems and verify that corrective procedures were effective.

Testing of the launch procedure was accomplished by lowering the vehicle on its launch rack through a well between the barge's pontoons. Propulsion motor activation by acoustic command, and release from the launch rack by electrical impulse through the support cable to solenoid-actuated release pins, were accomplished with little difficulty at various depths.

Some problems were encountered, however, in the deployment and retrieval of the cross-panel recovery net. The problem was resolved by modifying the net assembly to a single-panel net supported by two folding arms and by replacing the rigid pipe weights at the lower edge of the net with flexible leaded line (see Figure 6.2). This simpler arrangement, while not providing the first-pass capture capability of the cross net, has proved to be easy to deploy and retrieve without net entanglement. It can be almost completely unfolded while still in the hole.

There was early concern that, in addition to the capture probe, the tail fins and/or propeller might become tangled in the net making it very difficult to bring the vehicle and net up through the hole and possibly resulting in damage to the equipment. Thus far, this has not been the case. Actually, recovery of the vehicle with the capture probe enmeshed in the net has been fairly easy. The vehicle, being positive buoyant and held down by the net at the nose, floats upward, tail first, away

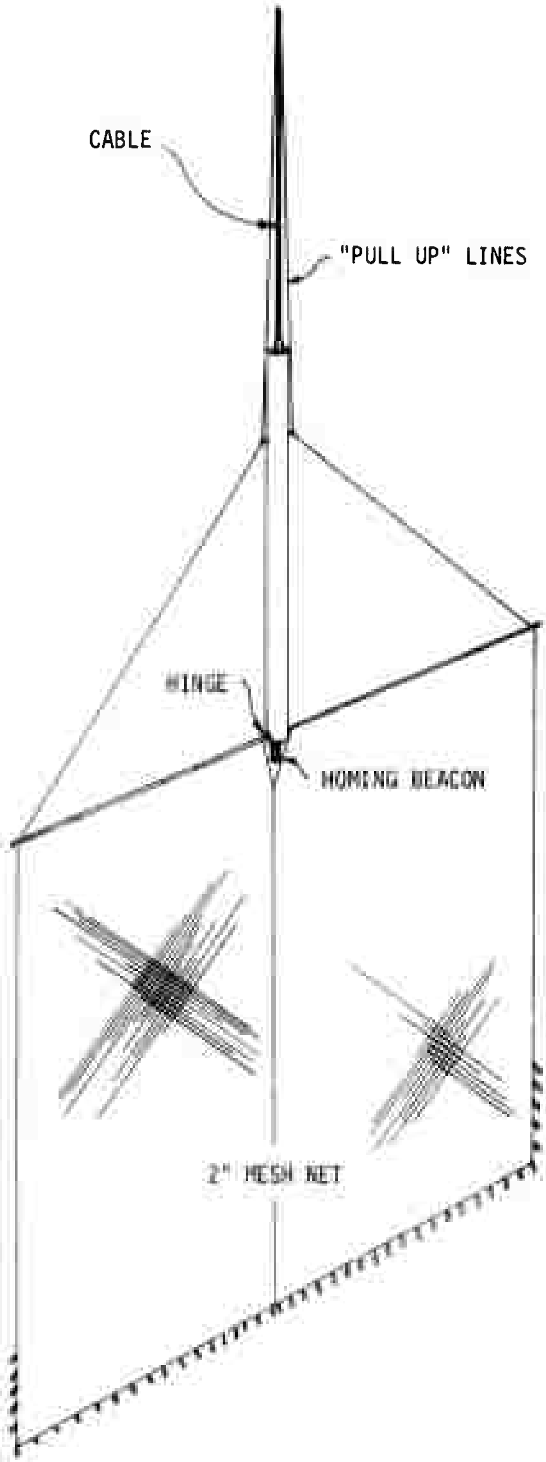


Figure 6.2. Recovery Net

from the net. This is so even while the net is being hauled up from the capture depth so long as it is done slowly. At about 10 to 15 feet below the bottom of the recovery hole the net's support arms are folded up against the center post. It is possible to position the net and vehicle so that the vehicle's longitudinal axis in aligned to the long dimension of the recovery hole with the net assembly at one end of the hole. The entire assembly, net and vehicle, can then be hoisted up through the hole until the vehicle is floating on the surface of the water.

The observed dynamic performance of UARS agrees well with that predicted by the analog computer simulation. With the vehicle trimmed 150 in.-lb nose heavy and a net positive buoyancy of 10 lb, the measured average pitch angle during level run is 1.5° nose down with an average up-elevator angle of 3.5°. This compares with computed angles of 1.5° nose down and 4.7° up-elevator during a level run with the same trim configuration. The measured vehicle velocity during level run is higher than the nominal design value (approximately 6.3 ft/sec rather than 5 ft/sec), while the measured power output from the propulsion motor (0.15 hp) is in the lower region of the values calculated for the design speed. This implies that the actual vehicle drag is in the lower region of the values calculated. The higher speed is not considered excessive for the operational purposes of the vehicle and is even desirable since future instrumentation may increase vehicle drag and reduce the speed somewhat.

The depth variations while operating at a preset depth during a straight run consist of short-term contributions (periods on the order of a few seconds) of less than 0.25 ft peak-to-peak amplitude superimposed on a slowly varying depth decrease of about 0.25 ft over a run length of four hours. This latter variation is believed to be caused by the decrease in propulsion motor speed which normally occurs as the battery voltage decreases during a run. The corresponding decrease in vehicle speed requires a larger nose-down angle-of-attack compensated by a larger depth error (the difference between the actual depth and the set depth).

The transition from dive or climb to level run is smooth, with no apparent tendency to overshoot in depth or pitch. Small pitch deviations on the order of ½° peak-to-peak are observed during level run with occassional deviations of 1° peak-to-peak. The latter deviations appear to be correlated with the rudder actuations. The dynamic roll control worked quite well in counteracting motor torque but requires additional damping, probably in the form of a roll rate feedback, to eliminate the small remaining roll oscillations. These are on the order of 1° peak-to-peak during level run with some peaks of 1.5° to 2° which are also correlated with rudder actuations. The gain in the roll control loop was varied during the runs in an attempt to find a setting which would provide adequate roll control without oscillations. It appears that the roll oscillations would damp out were it not for the slight coupling of rudder throws into the roll axis. This has been evidenced on runs in which the vehicle was under homing control and was headed directly toward the target beacon. Corrective rudder throw in this case is proportional to the

small measured angle to the target beacon and the oscillations are not observed. However, corrective rudder on straight runs under gyro control consists of short pulses (about 1 sec duration) of full rudder throw spaced at about 8 sec intervals. The cross-coupling of these rudder actuations into the roll axis is apparently sufficient to produce the roll oscillations observed. Some thought is being given to modifying the course gyro to provide a proportional output signal for driving the dc servo rudder actuator now being used (original design called for a solenoid-actuated rudder). This would alleviate the problem but may introduce small heading errors (magnitude dependent on control loop gain).

The acoustic tracking system performed well within the physical limits imposed by operation in Lake Washington. Radio interference was very high on the frequency band used for RF telemetry of data from the track ing buoys to the computer, making it very difficult to pick up the tracking pulses. In addition, the shallow water depth (~180 ft) limited the effective tracking range because of overlap of either bottom or surface reflected signals onto the direct path pulses at long ranges. The tracking buoy receivers reject tracking pulses which do not maintain proper phase coherency throughout an entire pulse. Overlapping of pulses generally produces unacceptable phase shifts during the latter portion of the pulse and thus such pulses are rejected and not retransmitted (by RF) to the computer. All vehicle runs were made at a depth of 80 ft and the tracking buoy hydrophones were suspended to a depth of approximately 70 ft. If we assume the lake to be an isovelocity medium and use the expression given in Section 4.3.4 to calculate the maximum horizontal separation without overlap, we obtain a distance of approximately 1700 ft. This agrees quite well with the performance during these tests.

In early vehicle runs, a failure in the phase coherence detection circuit in the vehicle's command receiver system resulted in the vehicle interpreting some garbled bottom echoes of its own tracking pulse as commands. After correcting this circuit, thousands of similar pulses were processed by the command system without a single false command being accepted.

The majority of runs made in the lake were devoted to testing of the vehicle homing system. However, the recovery net was deployed on only three of these runs. Of these three runs, the vehicle missed the net on the first run because of an error in setting the net to the correct vehicle run depth. It was captured in the net on the other two runs. On all other homing runs, only the homing beacon was deployed. One particular problem encountered was in reacquisition of the homing signal and correct bearing after passing under or near the homing beacon. While reacquisition of the homing beacon was always accomplished, the trajectory in doing so was erratic. Examination of the internal vehicle records revealed that intermittent invalid homing gates were being obtained after the vehicle had passed and was headed away from the beacon. By turning the homing beacon on and off during subsequent tests, it was determined that these invalid gates were being obtained from pulses reflected from

the shoreline, bridge pontoons, etc. This problem was corrected by lowering the beacon output power during the final phase of homing (to reduce the amount of reverberation above trip level) and by increasing the inhibit time after receipt of a valid pulse from 100 msec to 200 msec. Proper performance is illustrated in Figure 5.6.

It was also observed on the internal record that the bearing angle output from the homing receiver varied considerably even when the vehicle was on a trajectory straight toward the homing beacon (as observed from the acoustic tracking plot). This was at first thought to be a result of oversteering by the homing heading control, and the gain (rudder throw per unit angle output) in that portion of the control system was reduced. Although this resulted in some improvement, it was later determined that the variations were mainly a result of noise spikes being picked up in the homing receiver. The noise spikes themselves could not pass the pulse width requirement and were rejected, but when they occurred just prior to receipt of a direct pulse from the beacon, they also caused rejection of that pulse. Since the inhibit gate was not then activated, a phase calculation was made on the reverberation following the direct pulse. This, of course, would produce a large variation in the output phase angle, depending upon the source and nature of the reverberation. This problem was corrected by the addition of a circuit in the homing receiver which will reject a noise spike but not the main pulse from the beacon even though the noise spike occurs just prior to the pulse.

Aside from the system interactions already noted, the only other interaction problem has been with the flashing light beacon. The high voltage pulses used to excite the lamp in this unit show up in several of the low level signal circuits in the vehicle. In the first flashing light units, radiation from the charging circuit used to generate the high voltage pulses coupled into the homing system and saturated the receiver channels. A new charging circuit, increased shielding, and a power line filter were added to the flashing light unit in an attempt to cut down on the radiation. This was successful with respect to the radiation from the charging circuit, and while radiation is still detectable in the homing receivers, it is of such low level that it does not interfere with their performance. However, interference in vehicle systems from the high voltage pulses is still present. We hope to find a type of light which does not require the high voltage pulses but will provide sufficient light for a visual indication of vehicle passage under the hydrohole.

Performance of all of the other vehicle systems tested was satisfactory. While complete testing of the obstacle avoidance was precluded because of the open water, it was operational during most of the runs and no interaction problems or false obstacle avoidance signals were noted.

6.3 UARS ARCTIC TESTS

Immediately following the lake tests, the two UARS vehicles, the tracking computer, the tracking buoys and all of the associated equipment required for a UARS operation in the Arctic were packed and shipped by air freight to the Naval Arctic Research Laboratory (NARL) at Point Barrow, Alaska, for further shipment to Fletcher's Ice Island (T-3) in the central Arctic. The equipment, totaling 58 boxes and weighing some 10,000 lb, and four UARS project personnel were then transported from Barrow to T-3 on one of the normal C130 supply flights, arriving at T-3 on 10 April 1972. At this time, the island was located at approximately 84° North and 84° West.

Two of the project personnel had arrived at T-3 on a previous supply flight (20 March 1972), bringing with them 5000 lb of equipment, including the hot water ice hole cutter and other equipment for setting up the vehicle operations hydrohut. The area selected for vehicle operations was Colby Bay (see Figures 6.3 and 6.4) and the site chosen for the hydrohut was near the center of the bay and close to the first large pressure ridge across the bay's entrance.

The hydrohut had been prefabricated in 4 x 8 ft sections by NARL personnel at Point Barrow and then assembled into two half-sections near the main camp at T-3. The power generator hut was completely assembled at Barrow and flown to T-3 intact. A level area near the pressure ridge was bulldozed clear of snow and the two sections of the hydrohut and the power generator hut were then skidded by bulldozer from the main camp to the cleared area. Final installation of the hydrohut -- joining and caulking the two sections together, banking snow around the footings, assembly of work benches and assembly and installation of the overhead gantry hoist -- was accomplished by APL personnel prior to cutting the vehicle launch and recovery hole in the ice.

The hydrohut contained removable floor sections in one half of the building so that the hydrohole could be located directly below the building. The floor sections were kept in place when the hydrohole was not in use to provide more working area and to conserve heat. Figure 6.5 is a photograph of the hydrohut as set up for vehicle operations.

The task of cutting the hydrohole with the hot-water ice hole cutter is time consuming but not difficult (see Figure 6.6). A rectangular-grid cutting head measuring 4 ft on a side was used. Three passes were required to cut the 12-ft long by 4-ft wide hole. Although the top surface of the ice where the hydrohole was cut was reasonably smooth, the bottom surface was very irregular with the ice depth varying from 17 feet to 28 feet within the dimensions of the hole (see Figure 6.1).

Each pass of the cutter head leaves four 2-ft square ice columns floating free in the 4 x 4 ft hole and these must be removed (see Figure 6.7). Two techniques were used for their removal. The first consists

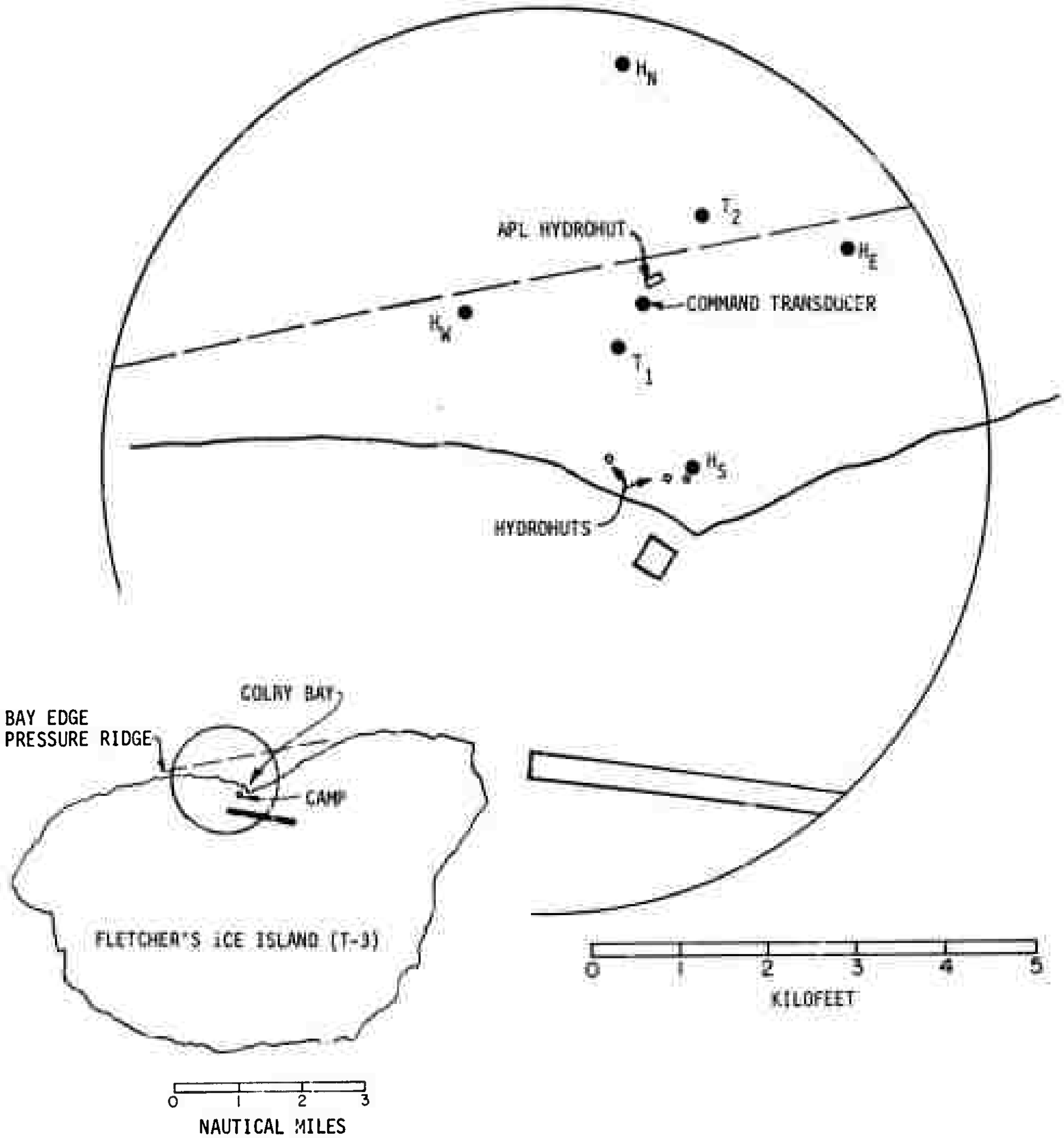


Figure 6.3. UARS System Geometry at Fletcher's Ice Island (T-3)

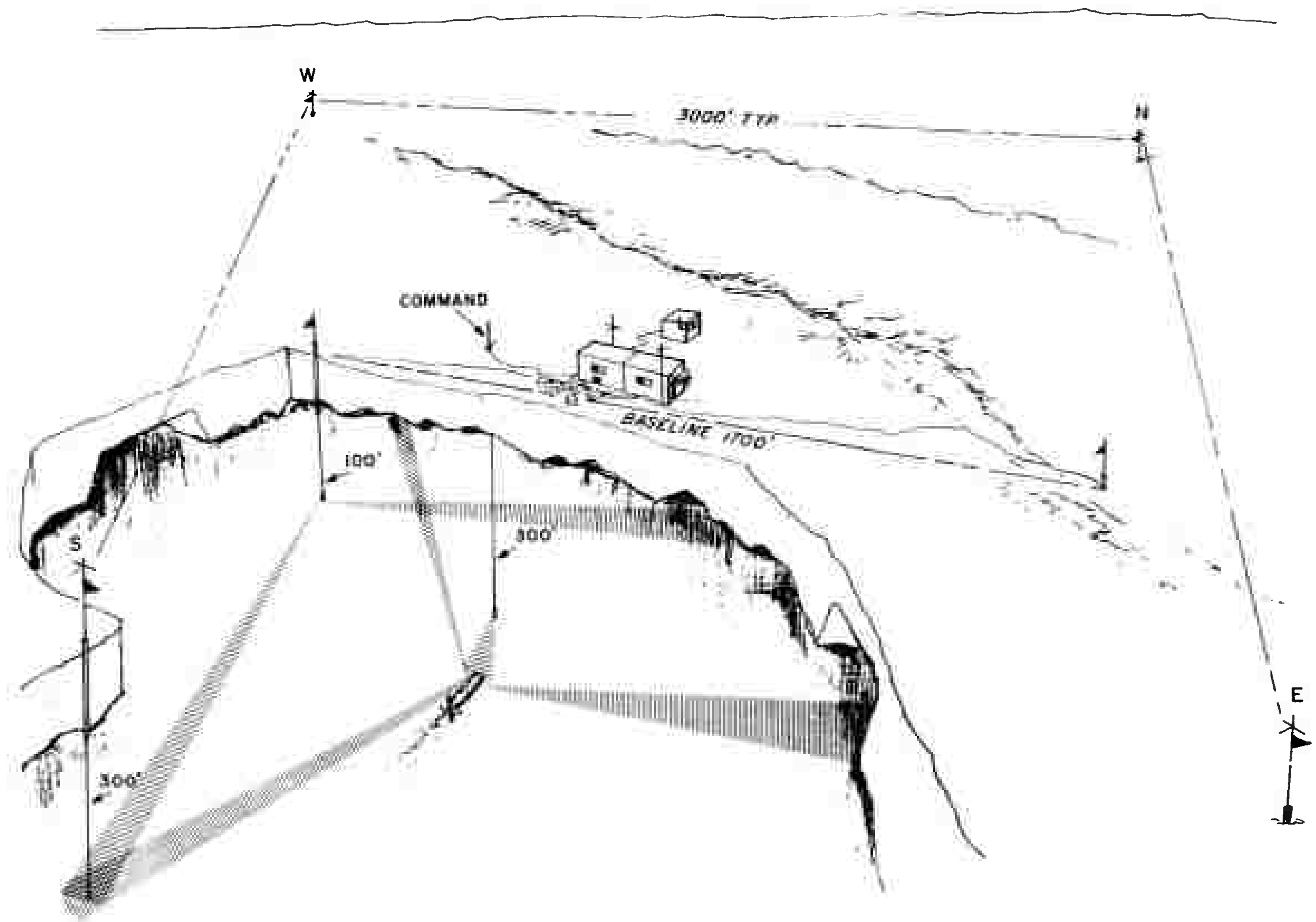


Figure 6.4. Test Area Geometry

Figure 6.5. Hydrohut (equipment just arrived)

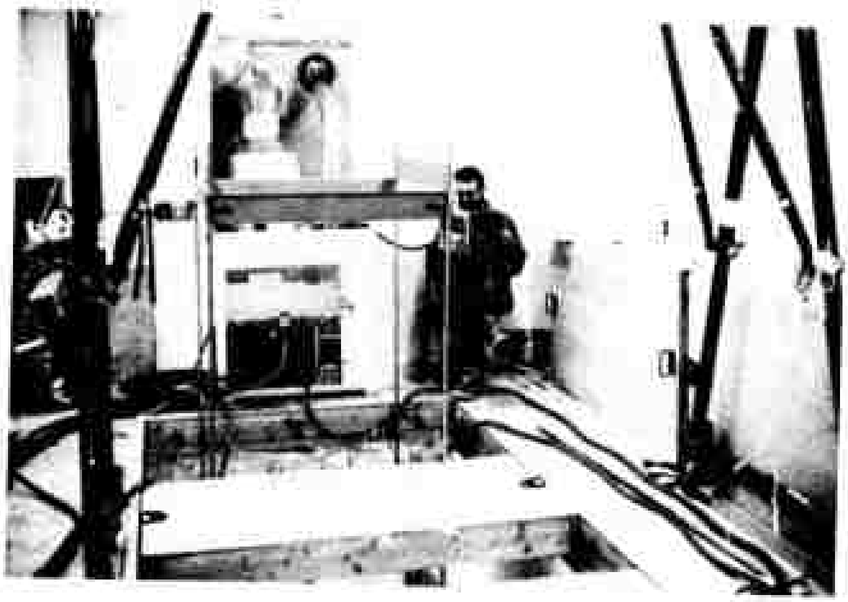


Figure 6.6. Cutting Hydrohole

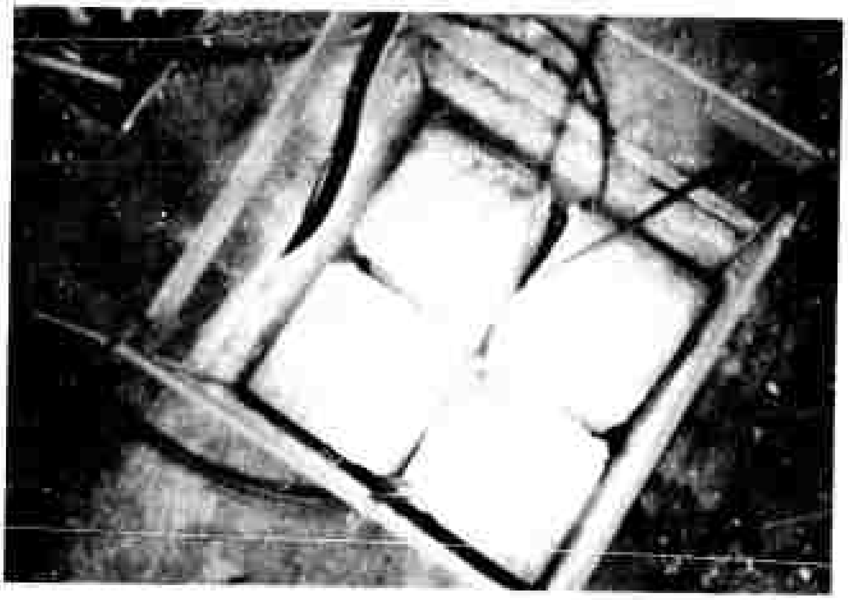


Figure 6.7. Ice Columns Formed in Cutting Operation

simply of lowering a weight from the overhead hoist on top of a column until it is pushed out the bottom of the hole where it topples and lies against the ice near the hole. This works fairly well on the first one or two columns, but can present problems on succeeding columns because the weight can slide off the column before it is free of the hole. If the weight or the line to the weight becomes wedged in the process, the situation becomes very difficult and may require additional ice cutting to free the weight. The second technique, while more laborious and time consuming than the first, does not present the difficulties just discussed. This consists of lifting the columns with a chain hoist and choker line, cutting the ice with an electric chain saw into manageable sections 5 to 6 ft long, and shoving them out the side door of the hydrohut (a special door near the hydrohole is generally included in all hydrohuts for the removal of ice from the hole). It should be noted, however, that a 2 x 2 x 5 ft block of ice weighs about 1000 lb and, while the blocks can be slid fairly easily on the floor, a bulldozer or other vehicle is required to move them away from the building.

One problem in cutting the deep hole was that of maintaining alignment between the three vertical cuts. The problem was aggravated in this particular case by the uneven bottom and extreme depth of the ice. When a vertical section is being cut and one side of the cutting head reaches open water before the other, there is a tendency for horizontal translation of the cutting head. This motion is restrained by the guide rods attached to the head but at these depths some bending of the rods does occur. The discontinuities were not severe, however, and the side walls were smoothed at the joints by trimming with a straight bar cutter head.

Once the hydrohole was cut and cleared of ice, the next task was that of keeping it from refreezing. This was accomplished in part by circulating water in the hole. This water had been passed through a heat exchanger (auto transmission cooler) mounted directly above the oil heater used to heat the building. This was sufficient to prevent ice growth on the walls of the hole but insufficient to prevent ice from forming on the surface of the water when the floor boards were in place over the hole. This latter problem was resolved by mounting an air duct containing a power fan in one of the removable floor section to blow warm air from near the ceiling of the room down and across the top of the water.

The preparations described above were completed by the time the main body of equipment and personnel arrived. The next order of business was the installation and checkout of the tracking equipment. The positions for the tracking buoys and the baseline transducers were marked. For the tracking buoys, we used a square array pattern of about 3100 feet on a side with the hydrohut in approximately the center of the array (see Figure 6.4). A gasoline motor-powered ice auger was used to cut the holes for installation of the tracking buoys, and the baseline and command transducer units.

In designing the electronics for the tracking buoys, we assumed that their ambient operating temperature would be near 0°C since the electronics are located in the lower portion of the buoy below the ice and completely surrounded by sea water. This proved not to be the case, apparently because of air circulation in the buoy despite the baffling provided. The lower temperatures caused detuning in the driver stages of the RF data telemetry transmitters to the point where several of the units ceased to operate. We adjusted the tuning of the units so that they would operate over a lower temperature range.

The winch used in the launch and recovery of the UARS vehicle was installed in the hydrohut near the hydrohole. This unit was also used for lowering a CTD (conductivity, temperature, pressure) probe on a daily basis to a depth of about 80 meters. The data from the probe were output in digital format on punched paper tape. A program was written for the tracking computer to read the tapes, calculate and plot profiles of salinity, sound velocity, temperature and density as a function of depth. The plots showed a remarkable consistency from day to day and a typical plot is shown in Figure 6.8. The sound velocity and density data are highly important to the vehicle operation. The sound velocity and its gradient are used in the tracking equations and for ray bending corrections. The density measurements, both at the hydrohole and at operating depths, are used in trimming the vehicle to obtain the desired buoyancy.

While the tracking equipment was being installed and checked out, all other equipment required for the operation of the UARS vehicle was unpacked and set up for operation or stored in the hydrohut. Preliminary checkout was made of all equipment to determine if any failures had occurred because of cold soaking or handling during transportation to the

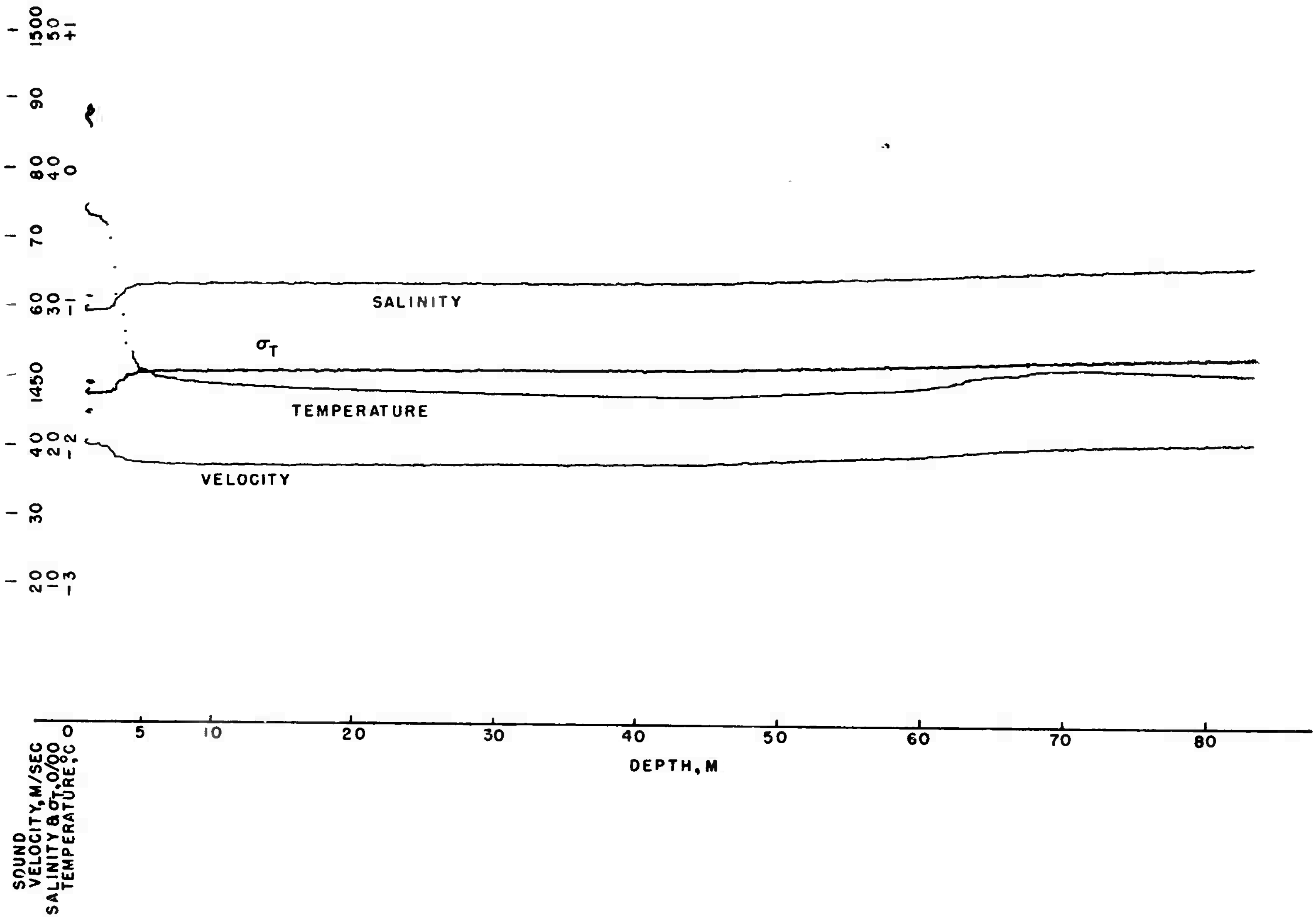


Figure 6.8. Vertical Profiles of Salinity, Temperature, and Sound Velocity from CTD Measurements

tracked positions and the position information obtained from surface surveys (transit bearings and rollatape distance measurements) were in good agreement, verifying proper logic performance.

Three free runs were then made with the vehicle. The first two runs were somewhat abbreviated because of unsatisfactory tracking system performance. The difficulty appeared to be insufficient sensitivity in the tracking buoys' acoustic receivers. Some improvement was observed between the first and second runs when the receiver sensitivity in each buoy was increased by changing some AGC circuitry. The AGC circuit was responding too strongly to reverberation following a tracking pulse and produced a low average receiver gain. The time constant in the AGC signal averaging circuit was increased to reduce this effect. Although tracking was improved on the second run, it was still considered unsatisfactory. A recalculation was made of the overall sensitivity of a tracking buoy's hydrophone and associated tuning unit. The insertion loss of the tuning unit was much higher than we had previously calculated. Changes were then made in the tracking buoy receiver circuits to increase the overall sensitivity by 18 dB and the AGC circuit was bypassed so that the receivers operated at a fixed gain. Tracking on the third run was greatly improved and was considered quite satisfactory.

The performance of the command system, although improved by changes made during the runs, is still not up to expectations based on previous field tests of breadboard systems and theoretical calculations. The problem again appears to be one of insufficient overall receiver sensitivity but, unlike the buoy receivers, the gain of the command receiver cannot be greatly increased because the receiver is located on the vehicle and is subjected to a higher background acoustic noise level. However, there is a very plausible explanation for the low sensitivities experienced in both the tracking and command systems which, if verified, will permit improvement in both systems. This is in regard to the radiation patterns of the tracking and command transducers when mounted on the vehicle. The patterns of the transducers by themselves have been measured and are essentially omnidirectional. However, there is evidence from the tracking record that the tracking pulse reception at the buoys was influenced by the vehicle heading. This indicates that some pattern anomalies exist in the vehicle transducers. Radiation patterns should be taken with the transducers mounted on the vehicle and changes made in the mounting configuration, if required, to achieve a more nearly omnidirectional coverage.

In the first two runs some difficulties were experienced with the homing system operation in obtaining an immediate reacquisition and a new intercept angle after missing the net. This was not the same problem experienced in the lake tests in that the vehicle trajectory after missing the net was not erratic but tended to follow a definite pattern; that is, after missing the net, the vehicle would make several large circles (400 to 500 ft diameter) around the net and then proceed to make a new pass at the net. As luck would have it, the combination of approach angle and net rotation presented a series of low intercept angle passes resulting in a rather large number of passes being made before a net capture

was obtained (six passes on the first run). The behavior was at first diagnosed as being the result of a low sensitivity region in the side pattern of the sense transducer. This would permit homing, under certain orientations of the vehicle with respect to the beacon, on pulses reflected from the keel of the large pressure ridge near the hydrohole. The explanation as to how this could produce the observed circular trajectory is lengthy and will not be pursued here. Suffice it to say that the corrective procedure taken on the basis of this diagnosis was ineffective and the homing trajectory on the second run was similar to the first, although fewer net misses occurred before capture.

Prior to the third free run, two more tethered runs were made with the vehicle and, in addition, the homing bearing transducer was installed in a trainable housing while connected by cable to the UARS vehicle on the surface. These tests were conducted to locate the source of the homing problem and to determine if corrective procedures were effective. The homing beacon, as before, was operated from a hydrohole near the main camp during these tests. It should be noted here that after the lake runs, an adjustment had been made in the homing logic circuits to reduce the time-of-arrival requirement on pulses from the bearing and sense channels in order to increase the bearing acceptance angle (from ±45° to ±60° with respect to the vehicle axis). Previous tests of the homing system (not mounted in the vehicle) had indicated that satisfactory operation could be obtained over the wider angle. An increased acceptance angle is desirable since it would make it easier for the homing system to achieve initial acquisition when in the homing search mode. In these tests, there was evidence of reverse steering (i.e., right turn output from the homing receiver with the beacon to the left of the vehicle heading) at the higher acceptance angles. The time-of-arrival circuit was readjusted for the ±45° bearing acceptance angle and the reverse steering condition disappeared. On the third free run, the homing system performed as designed (see homing trajectory of third run in Figure 6.9).

Recovery of the vehicle after capture in the net presented no problems. However, there were some tense moments on the first recovery, when the vehicle became free of the net after being hoisted from the capture depth (250 ft) to about 15 feet below the hydrohole. It then floated up and across one end of the hydrohole and became lodged in the ice undersurface with the tail of the vehicle sticking out into the hydrohole. Two scuba divers were standing by in these operations, and one of them dived down to the vehicle and passed a line around the vehicle forward of the tail fins. A weight was then slid down that line with a tag line. The weight was lowered until it pulled the vehicle below the bottom of the hydrohole. Then the weight was pulled up by the tag line, which allowed the vehicle to rise. It came up in perfect recovery position on top of the water. The shape of the recovery probe on the nose of the vehicle was then modified by lengthening the tip in front of the barbs. This makes it difficult to extract the probe from the net mannually, but also greatly reduces the probability of self-release during recovery.

The sensitivity of the obstacle avoidance receiver was observed to be a little high. Several obstacle avoidance signals were obtained at the 150-ft run depth even though the deepest ice keel in the path of the

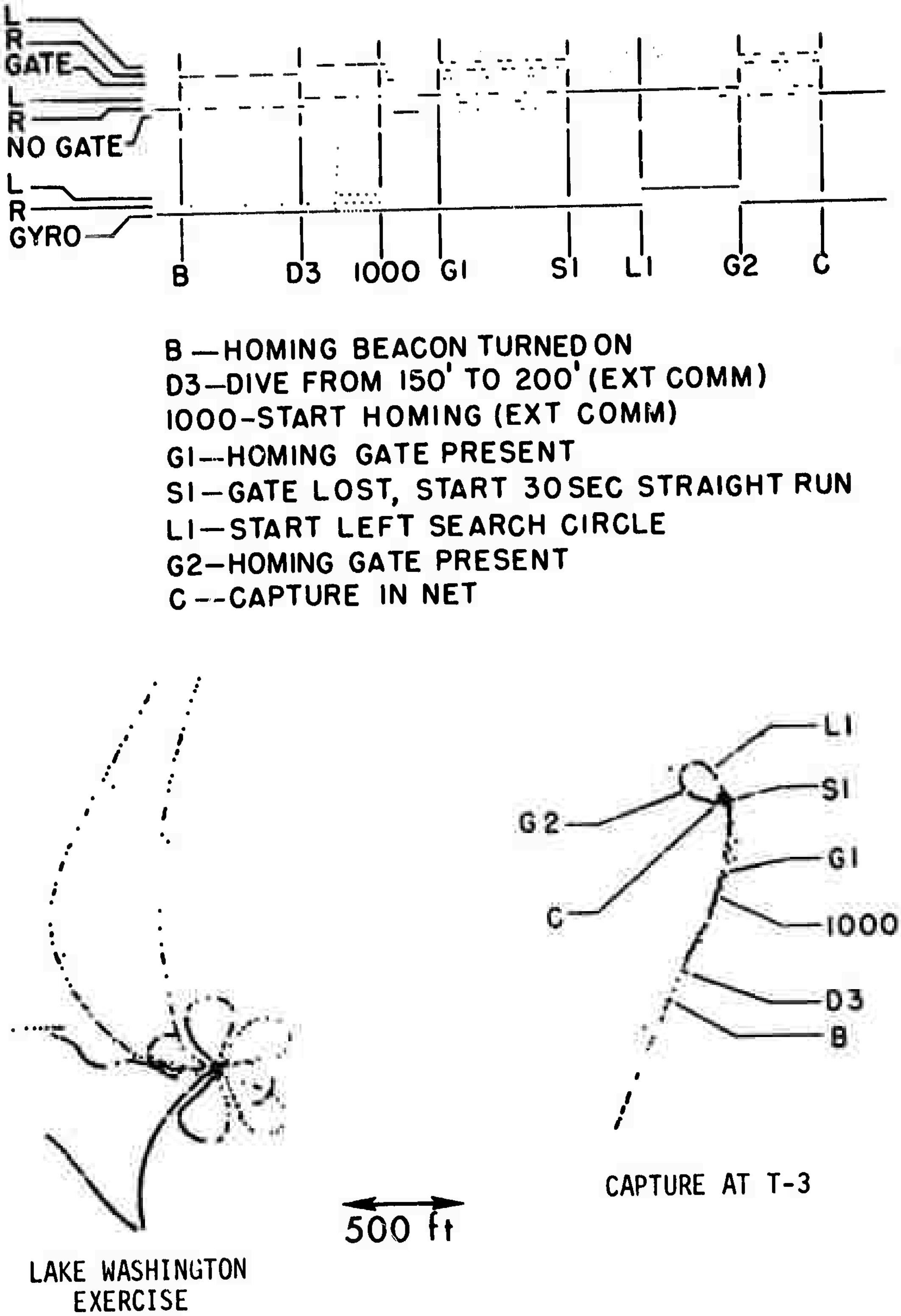


Figure 6.9. UARS Homing Trajectories

vehicle, as determined from the profiler recording, was only about 80 ft. This sensitivity can be easily reduced, however, and presents no problem.

The clarity of the water in the Arctic is quite remarkable. The lights on both the launch rack and the net were clearly visible and illuminated the vehicle when in their vicinity even at a depth of 250 ft (the maximum depth to which they were lowered). The vehicle's flashing light, when activated, was also clearly visible at all run depths and marked the trajectory of the vehicle as it passed under the hydrohole in its homing operation.

On the third vehicle run, everything proceeded as planned. A radial trajectory pattern was used so that heading changes via acoustic command need only be made when the vehicle was near the hydrohole. The five minute loss-of-command 180° turn sequence was used for making the turns at the outer ends of the trajectories. In this case, a 183° turn was used so that the outgoing and incoming trajectories crossed near the hydrohole. Heading changes of 30° were commanded on alternate passages of the vehicle by the hydrohole and resulted in the trajectory pattern shown in Figure 6.10. On the 7th such command, a 15° heading change was commanded rather than 30° so that the following trajectories would interleave those already run. The run was terminated after approximately 4 hours by a command to start homing. The homing trajectory was precisely as it should have been (see Figure 6.9). The vehicle missed on the first approach because of a low intercept angle and then lost the homing signal. It circled and reacquired the signal, made a second approach at a new angle, and was caught in the net.

The UARS position was computed and plotted at 2-sec intervals throughout the run (Figure 6.10). A printout of the corresponding UARS coordinates and telemetered information was made simultaneously. A portion of this printout (near "17" in Figure 6.10) is shown in Figure 6.11. The column following the coordinates indicates the first three tracking buoys to receive the tracking information, in order of reception. The next column displays the telemetered data. The first two digits identify the data source and the next two digits contain the information. The 04 digits, for example, identify a tracking pulse containing data from the center profile beam. The next two digits give the magnitude of the distance in octal format, which is equivalent to a 6-bit binary word as discussed in Section 5.10.

A plot of the center beam under-ice profile data taken during a traverse that was approximately normal to the pressure ridges is shown in Figure 6.12. Also shown in the figure is a plot of the surface topography taken over the same path using standard surveying equipment (i.e., transit, level rod and chain). Although both ice and snow elevations were taken on the surface survey, only the ice elevations are plotted. It is interesting to compare the vehicle's measurement of the under-ice profile with the manual measurement of the upper-ice surface profile. The vehicle took a data point (considering only the center beam) at each foot of travel and required about 12 minutes to cover the 4500 foot trajectory in the plot. Following

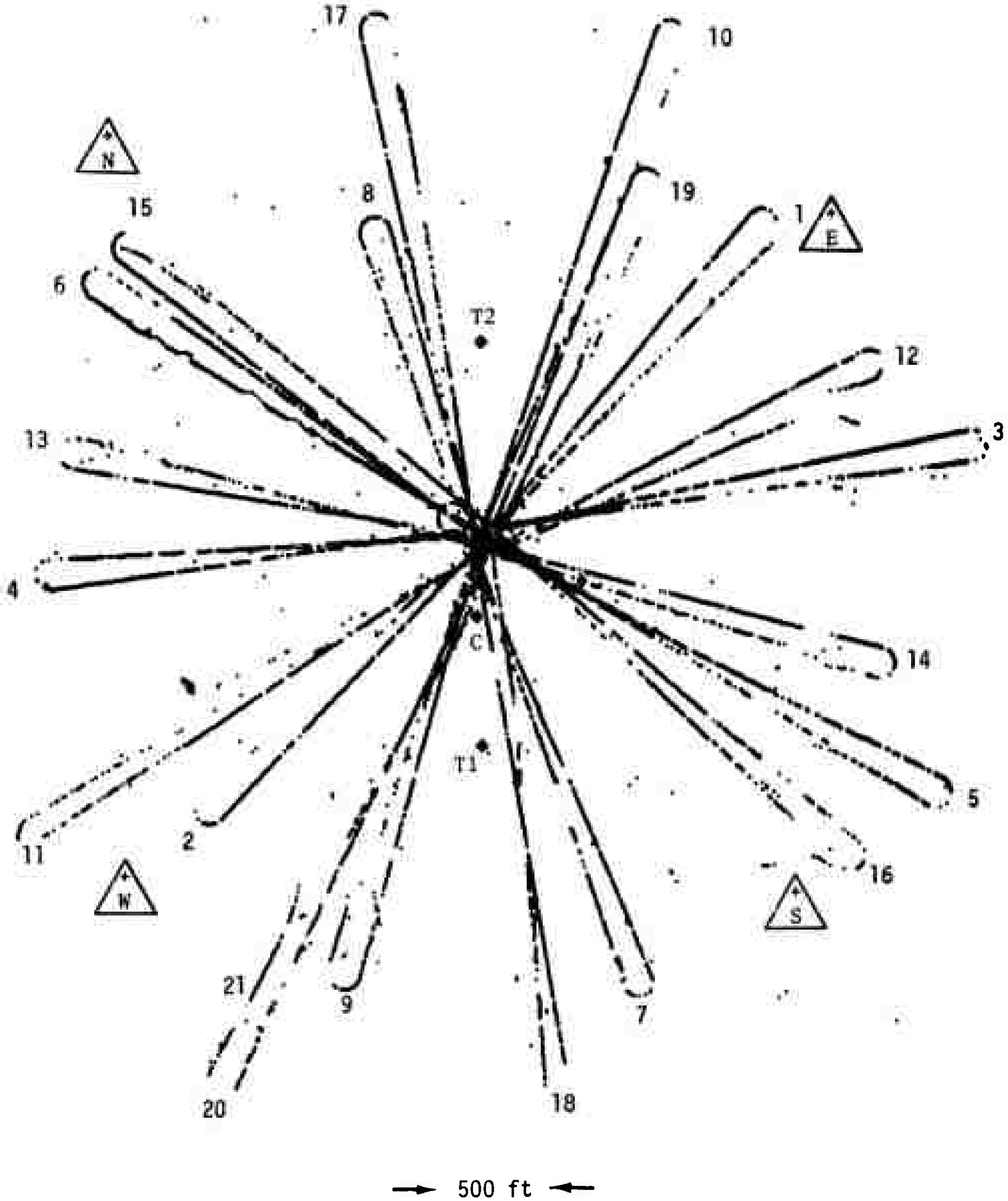


Figure 6.10. Real-Time UARS Tracking Data,
Run No. 3, 9 May 1972

TIME			RTIME	X	Y	CODES			
14	20	32	6516	-76	2355	NEW	0407		
14	20	34	6517	-460	2790	NEW	0400		
14	20	36	6518	-462	2802	NEW	0400		
14	20	38	6519	-464	2813	NEW	0410		
14	20	40	6520	-467	2824	NEW	0410		
14	20	42	6521	-469	2836	NEW	0410		
14	20	44	6522	-472	2847	NEW	0410		
14	20	46	6523	-474	2859	NEW	0411		
14	20	48	6524	-477	2870	NEW	0411		
14	20	50	6525	-480	2882	NEW	0407		
14	20	52	6526	-482	2894	NEW	0410		
14	20	54	6527	-484	2905	NEW	0407		
14	20	56	6528	-487	2916	NEW	0407		
14	20	58	6529	-489	2928	NEW	0407		
14	21	0	6530	-491	2939	NEW	0407		
14	21	2	6531	-493	2951	NEW	0410		
14	21	4	6532	-496	2963	NEW	0411		
14	21	6	6533	-498	2974	NEW	0411		
14	21	8	6534	-501	2985	NEW	0411		
14	21	10	6535	-503	2997	NEW	0411		
14	21	12	6536	-505	3009	NEW	0412		
14	21	14	6537	-508	3020	NEW	0400		
14	21	16	6538	-510	3031	NEW	0412		
14	21	18	6539	-513	3043	NEW	0400		
14	21	20	6540	-515	3055	NEW	0412		
14	21	22	6541	-518	3066	NEW	0400		
14	21	24	6542	-520	3078	NEW	0400		
14	21	26	6543	-522	3089	NEW	0411	0502	
14	21	28	6544	-525	3100	NEW	0412	0600	
14	21	30	6545	-526	3112	NEW	0412	0502	
14	21	32	6546	-525	3124	NEW	0412	0600	
14	21	34	6547	-523	3134	EWS	0411	0502	
14	21	36	6548	-519	3145	NEW	0411	0600	
14	21	38	6549	-513	3154	NEW	0412	0502	
14	21	40	6550	-506	3163	NEW	0411	0600	
14	21	42	6551	-498	3170	NEW	0411	0502	
14	21	44	6552					0411	0600
14	21	46	6553	-478	3181	NEW	0411	0502	
14	21	48	6554	-467	3184	NEW	0411	0600	
14	21	50	6555	-456	3183	NEW	0400	0502	
14	21	52	6556	-446	3182	NES	0410	0600	
14	21	54	6557	-435	3181	NEW	0407	0502	

Figure 6.11. Computer Printout of Real-Time Tracking/Communication Link Data

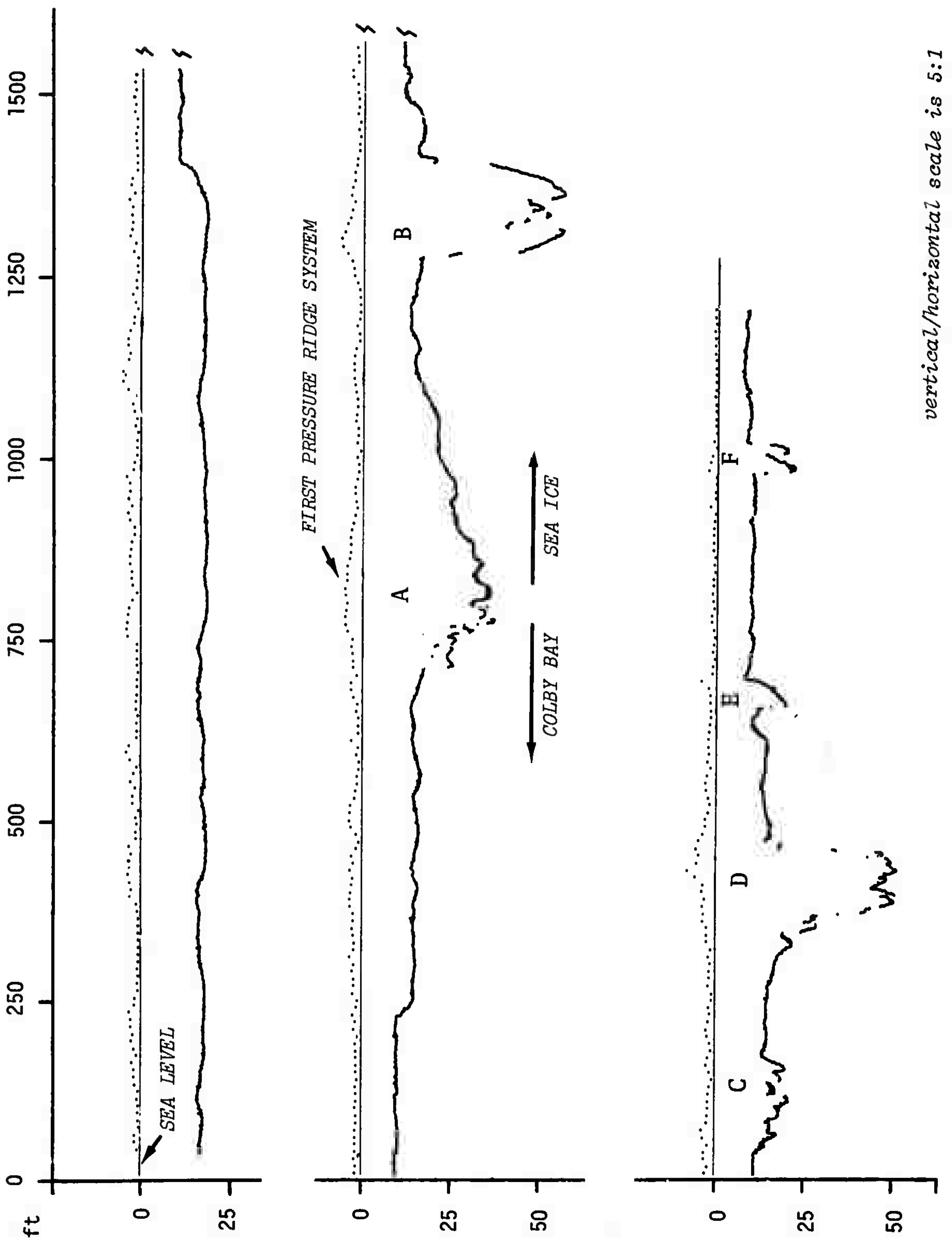


Figure 6.12. Upper and Lower Surface Profiles of Pressure Ridged Ice Taken During UARS Operation at Ice Island T-3 in Spring 1972

the run, it took only a few minutes for the computer to read and plot the data shown. On the other hand, the surface survey required five men and took nearly a day to complete with elevations being taken at 10-ft intervals. It then required about 1 day to transcribe, reduce, and plot the data.

The elevation data plotted in Figure 6.12 provides a subjective means of evaluating the correlation of the upper and lower surfaces. The pressure ridge at the indicated "division" between Colby Bay and sea ice is a multiyear pressure ridge. The other pressure ridges shown appeared to be new, first-year ridging. The ratio of the maximum lower-ice surface elevation (below sea level) to the maximum upper surface ice elevation associated with each ridge along the measurement traverse for the six pressure ridges is

A - 8.60
B - 9.57
C - 8.33
D - 6.51
E - 5.61
F - 11.72

Similar ratios, based upon maximum elevation of the snow surfaces at each pressure ridge crossing are

A - 6.88
B - 9.25
C - 6.08
D - 5.97
E - 4.44
F - 5.32

Some idea of how close these ridges are to isostatic equilibrium can be gained by correcting the observed upper-ice elevation for the snow overburden. The snow density was approximately half that of the sea ice and the corresponding ratio of pressure ridge keel depth to "equivalent" ridge elevations is

A - 7.64
B - 9.41
C - 6.43
D - 6.23
E - 4.96
F - 7.56

These ratios can be compared with the depth to freeboard elevation ratio expected of level homogeneous sea ice, which is very near 7.8. The mean value of this last group is essentially 7.0. Previous values of pressure ridge keels to sail elevation ratios of 3 to 5 have been reported (Refs. 8, 9 and 10).

The quality of the data from the profiles was outstanding. The tight acoustic beam and stable behavior of the UARS allow fine grain resolution of the ice surface elevation. On the last run, for example, the UARS followed a run program in which many traverses were made in the vicinity of the hydrohole (see Figure 6.10). On five of the traverses, the middle beam of the UARS profiler defined the water surface (and sides) of the 4 x 12 x 28 ft deep hydrohole as it passed some 150 feet underneath. The numerical data taken directly under the hydrohole indicates a level plane (within one quantization bit) as, indeed, the water surface is.

The dynamic performance of the vehicle with respect to pitch, roll, depth stability, etc. was as designed and is reported in Section 6.2. In addition to profile data, ocean temperature data were taken on all runs using the thermistor controlled Wien bridge oscillator temperature sensor. The temperature was recorded with a resolution of about 0.5 millidegrees Centigrade and data points were taken at five times per second. Other vehicle performance data was taken as usual.

The four tracking hydrophone buoys, the command transducer, and the two tracking transducers were frozen into ice from 9 to 17 feet thick. These units were recovered on 13 and 14 May using the previously described thermal corer system. The field party returned from the ice on 21 May completing a most successful and ambitious program.

REFERENCES

1. Nodland, W.E., "A General Description of the Self-Propelled Underwater Research Vehicle (SPURV)," APL-UW Report 6814, 17 May 1968

2. Pederson, A.M., "A Digital Depth Reference," APL-UW Internal Report 6813, 8 February 1968

3. Nodland, W.E., "An Analysis of the Depth Control System for a Self-Propelled Underwater Research Vehicle Utilizing the Dual Input Describing Function," a thesis for the degree of Master of Science in Electrical Engineering, University of Washington, 1965

4. Sater, J.E., "The Arctic Basin," Arctic Institute of North America, Tidewater Publishing Corp., May 1963

5. Pederson, A.M., "SPURV Instrumentation System," APL-UW Internal Report 6815, 4 March 1968

6. Francois, R.E. and W.E. Nodland, "Unmanned Arctic Research Submersible System Development Report, Phase I," Technical Report APL-UW 7108, 26 July 1971

7. "Arctic Technology Development at the University of Washington," Division of Marine Resources, 31 December 1971

8. Kovacs, A., "On Pressured Sea Ice," International Sea Ice Conference, Reykjavik, Iceland, 1971 (in press)

9. Weeks, W.F., A. Kovacs and W.D. Hibler III, "Pressure Ridge Characteristics in the Arctic Coastal Environment," Proceed. First Internat. Conf. on Port and Ocean Engineering under Arctic Conditions (Technical Univ. Norway, 23-30 August 1971), 32 pp., 1972

10. Wittmann, W. and J.J. Schule, "Comments on the Mass Budget of Arctic Pack Ice," Proceed. Symp. Arctic Heat Budget and Atmos. Circulation, Rand Corporation (RM-5233-NSF), 215-246, 1966